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HIGH SPEED OPTICAL STORAGE TECHNOLOGY

Eastman Kodak Company

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13. ABSTRACT (Maximum 200 words)

The objective of the effort was to investigate and demonstrate by means of a breadboard model, a high performance 14-inch digital optical system with the following specifications:

- 25 Mbps minimum sustained user data rate,
- 5.0 GB per side minimum user data capacity,
- Double-sided media capacity of 10.0 GigaBytes,
- Magneto-Optic media which is erasable and reusable many times with a design goal of 10,000 write/read/erase cycles, and
- Effective corrected bit error rate of less than 1 bit in 10^{12} bits

In order to achieve a low life cycle cost system, off-the-shelf technology and utilization of commercial developments were employed. This approach was realized in the optical head design and the tracking servo system. Successful completion of this effort has laid the foundation for a next-generation optical jukebox system.

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Table of Contents

Section 1 Approach, Objectives & Goals

Objective

The objective of the High Speed Optical Storage Contract (HOST) was to investigate and demonstrate by means of a breadboard model, a high performance 14-inch digital optical system with the following specifications:

- 25 Mbps minimum sustained user data rate
- 50 Mbps burst data rate
- 5.0 GB per side minimum user data capacity
- Double sided media capacity of 10.0 GigaBytes
- Magneto-Optic media which is erasable and reusable many times, with a design goal of 10,000 write/read/erase cycles
- Effective corrected bit error rate of less than 1 bit in 10^{12} bits.

Approach

In order to achieve a low life cycle cost system, off-the-shelf technology and utilization of commercial developments were employed wherever possible. This approach was realized in the optical head design and the tracking servo system which are both detailed later in this report.

Goals

The goal of the HOST contract was to design a system architecture, develop subsystem components, and enhance laboratory system characterization test beds to provide the core platform needed which will enable commercialization of a magneto-optical product.

Previous research and development accomplishments at Kodak have demonstrated single channel high data rate head/media interface (HMI) designs and media durability has been tested to be in the 1 million write/read/erase cycle range. To achieve the goals of the contract however, it became obvious that a viable tracking system was needed. Therefore, emphasis was placed on developing a tracking system which would provide the capability to perform enhanced HMI and system analysis/design testing.

Section 2 Results

2.1 Optical Head

Objective

The goal of this effort was to design, build, and demonstrate an optical head that was capable of optimized performance on all Kodak media. The head was to provide performance equal to the best that had been observed on 14-inch MO glass media, 14-inch phase change on glass or aluminum as well as smaller formats. This high performance data detection achieves its flexibility through a combination of careful electrical design and novel optical techniques. The head is also to have servo detectors that are replaceable modules to be optimized for different media or incorporate new servo detection techniques. The head also has a small spot FWHM < 0.8 μm, high power to the disk > 35 mW, and high bandwidth data detectors > 35 MHz so that it can also demonstrate high capacity and high transfer rate.

Design

This head design leverages our Spaceborne Optical Disk Recorder (SODR) demonstration MO head and high speed CD writing head to fulfill the HOST contract requirements and provide a flexible technology demonstration platform. The head design specifications are shown in Table 2.1-1. A layout of the head is shown in Figure 2.1-1. Although the design emphasizes multifunction operation, most of our discussion will concentrate on its performance with MO media. The achromatic integral head design is designed to be compatible with existing Kodak optical heads test fixtures.

Incident Path

The incident path to the disk is very similar to Kodak's proven KOH head design which is used in Kodak's 14-inch (KOH) and CD (KOH-CD) optical recording products.

After an extensive survey of high power (> 100 mW) single spatial mode laser diodes, the Spectra Diode Labs SDL5411-G1 laser was selected because of its short wavelength (780 nm), low noise, high efficiency, and reliability. This devices specifications are shown in Appendix A. We also have a demonstrated record of success working with Spectra Diode Labs. Two SDL-5411G1 lasers were tested for intensity noise in our bench top optical head. The lasers were exceptionally quiet (<-128 dB/Hz) for typical read powers and optical feedback levels. We have also learned that Spectra Diode Labs has made some process improvements that has improved their reliability (MTTF > 400 KHrs. @ 100 mW, 25 °C) and yield (lower cost). Currently the lasers are ≈ $150 in small quantities.

Integral Head Design	Achromatic Optical Path
Wavelength	780 ± 5 nm
Output Power	40 mW CW
Numerical Aperture	0.55
Spot Size Max FWHM	0.85 x 0.89 μm
Detection Systems	Replaceable Modules
Focus method	Spot size
Tracking Grooved media	Phase tracking
Glass disk	Wobbled density
MO Detection	Current Difference @ RF w/ Phase Compensation
WO Detection	Current Sum @ RF Det.
Compatible with All EK Media	CD-WO[1], 14" WO, 5 1/4" MO[2], and 14" MO

Table 2.1-1 HOST Optical Head Design Goals

[1] WO: Write-Once

[2] MO: Magneto-Optic

The collimating lens is a Kodak precision glass molded aspheric lens. This lens was selected after a trade-off of head efficiency and spot size. Its longer focal length (7.5 mm) significantly reduced the spot size below the design goals as well as improved tolerancing of the laser alignment.

The most important consideration for the optical stack is that it be achromatic over the laser's expected wavelength range as a function of power and temperature.[3,4] The design of the optical stack geometry and coatings are shown in Figure 2.1-1. The optical stack was procured from OCLI, Inc., and met all of our specifications including minimizing phase shift as a function of wavelength.

The focus and tracking actuator with an Olympus 0.55 NA objective lens were procured from an internal supply. This unit is very similar to the units (0.5 NA) used in Kodak commercial products.

The focal spot shift and Strehl ratio at the disk were modeled as a function of laser wavelength. Acceptable performance was found (Strehl ratio > 0.95) for wavelength of ± 5 nm. The modeling of the optical head performance also predicted the optical head efficiency would be 34% with a spot size of 0.78 μm in-track by 0.79 μm cross-track.

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[3]E. C. Gage and B. J. Bartholomeusz, "Directional Asymmetries due to Write-Laser Mode Hopping during Optical Recording," J. Appl. Phys. 69, 569 (1991).

[4]D. B. Kay, S. B. Chase, E. C. Gage, and B. D. Silverstein, "Write Noise from Optical Heads with Non-Achromatic Beam Expansion Prisms," Optical Data Storage Conf., paper TuD2-1 (1991).

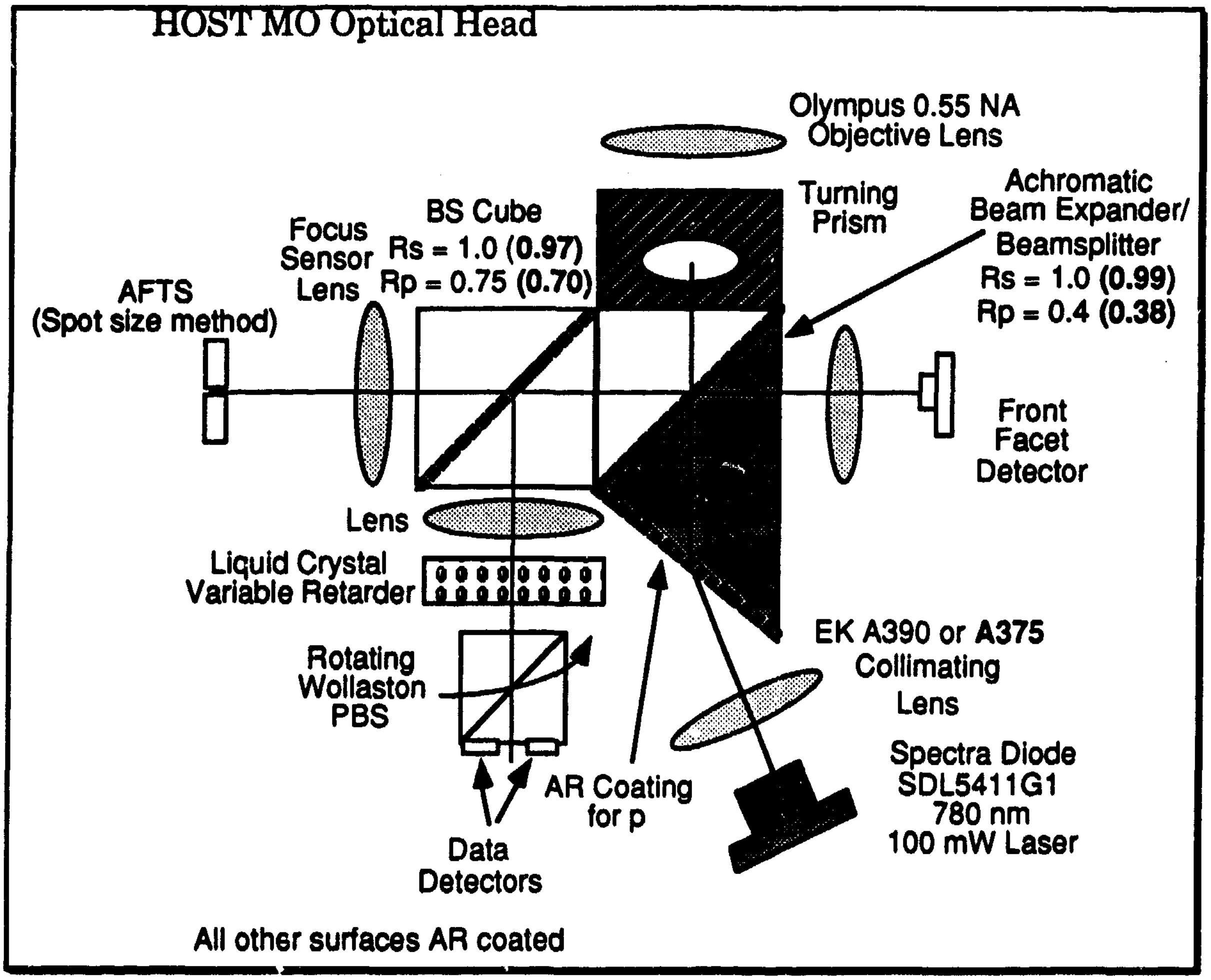


Figure 2.1-1 A schematic layout of the HOST optical head is shown. (The values in parenthesis are actual measured values.)

Detection Subsystems

The head design has independent focus and data detection so that each subsystem can be upgraded as technology evolves.

The focus detection method (spot size technique) was selected because of its simplicity and ability to perform focus and phase tracking detection in one detector array. Because it senses the far field intensity pattern, this method can be sensitive to disk birefringence. This replaceable module is most appropriate for glass disks. A layout of this Kodak proprietary design is shown in Appendix A. A new focus detection scheme, modified dual half aperture is being investigated. This shows some promise of being higher performance and compatible with write-once media or polycarbonate substrate disks. This will allow the new head to be a high performance universal head. This focus detection method is currently being prototyped with promising early results. This subassembly will be integrated into the head when we investigate coversheeted magneto-optic media.

For the phase compensation in the data detection system, we evaluated variable retarders from UCE Inc., Meadowlark Optics, and New Focus. Because of its high transmission and stable performance the Meadowlark liquid crystal variable retarder was chosen for optical head design. The retardance versus applied voltage for liquid crystal variable retarders from Meadowlark Optics is shown in Appendix A. They cover the birefringence range we require and show a monotonic dependence on drive voltage. The transmission > 98% was also acceptable. To maximize the flexibility of the detection system without using custom detectors, the polarization analysis is performed with a Wollaston prism from Karl Lambrecht. The polarizer has high transmission (> 98%) with extinction ratios of greater than 10^4:1. Future designs may incorporate microprism polarizer to significantly reduce the size of the detection system. The detectors are EG&G FFD-100's. These have bandwidth of > 300 MHz and high responsivity > 0.5 mA/mW.

Extensive modeling of the data channel was performed.[5] The predicted CNR is 62 dB at 1.5 mW read power, which is within 1 dB of the measured result, see section III. The signal to noise is limited by shot noise and media noise. Thus the head is performance optimized.

[5]E. C. Gage, "Comparison of Polarization Readout Techniques for Magneto-Optic Systems," Joint Int. Symp. Opt. Memory and Opt. Data Storage, paper F2.2 (1993).

Head Electronics

For the laser diodes, a high frequency injection system using an existing commercial system from Hewlett Packard was selected. This is a versatile system that we could emulate on a small surface mount board for a commercial system. It provides the ability to select the injection frequency that leads to the lowest laser noise. For the data in this report, the injection was 50 mA peak to peak at 520 MHz.

Four on-head printed circuit boards were designed in-house for this application. They consist of the main head board, RF preamplifier board, the front facet monitor preamplifier board, and the laser driver board. The data and front facet monitor provide both a dc and ac coupled outputs. This will allow optimization for different read channels. The bandwidth of these channels exceeds 40 MHz, which will support a read channel of up to 80 Mbits/sec. The gain matching between the two read channels is better than 0.2 dB at the input to the differential RF amplifier. This should allow very good common mode noise rejection.

Performance

The measured specifications of HOST magneto-optical head are shown in Table 2.1-2. The head has a very nice focused spot with a Strehl ratio of 0.96 and a spot size of 0.8 by 0.71 μm. This is about 10% smaller than our current MO tester heads. The head efficiency was 33.4%, which allows up to 35 mW to the disk. With current MO on glass media this would allow recording up to speeds on the order of 40 Mbits/s. The focus sensor sensitivity, front facet efficiency, and data detectors showed signals within the predicted range. A plot of focus error signal is shown below in Figure 2.1-2.

Head Efficiency	33.4%
Max Write/Erase Power	36 mW
Wavelength	784 nm @ 100 mW
Spot Size	0.71 x 0.80 µm
Strehl Ratio	0.96
Head Mass	169 gm
Focus Error Signal	0.323 mV/µm
Front Facet Monitor	0.28 V/mW

Table 2.1-2 Optical Head Specifications

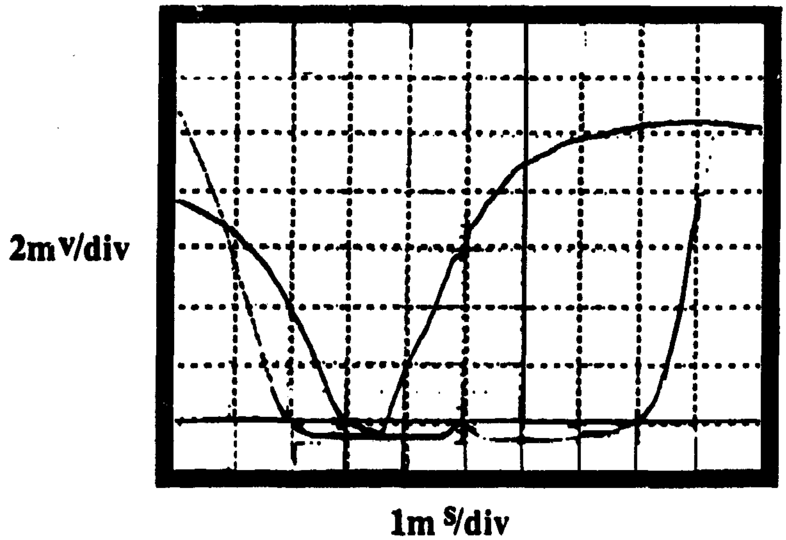


Figure 2.1-2 Plot of Focus Error Signal

2.2 Track Following Servo for Magneto Optic Disk

Objectives

The objective of this task was to design support electronics to enable formatting of blank disks and develop servo electronics to demonstrate a sampled servo track following system. This servo system provided automatic track following allowing

Background

Unlike grooved CD and 5 1/4 MO disks, the Kodak experimental 14 inch MO disk has no grooves, and therefore provides no continuous push-pull tracking error signal detector. Similar to the Kodak 6800 phase change 14 optical disk media, the disks must be preformatted on a precision "spin stand" to provide marks interspersed in the data tracks which are subsequently used to determine tracking error of the read laser. Unlike phase change media, the MO media will not support dedicated detectors for tracking error sensing.

A position error sample (PES) must be derived from the data channels via sampling the playback signal induced by the preformatted tracking marks (also called *"tracking pads"*).

A complete tracking pad consists of a sync mark followed by two marks offset symmetrically from the nominal track centerline. *(This Technique is Analogous to the Sector Servo Approach in Magnetic Disk Systems)*

Preliminary Format for Spin Stand Testing

Unlike the 14-inch phase change disk format found in the Kodak System 6800 optical disk recorder which uses spiral written tracks, the tracking servo developed under this project uses circular tracks with a PES density similar to the 6800 format. Since spiral tracks require constant velocity in the radial direction during formatting, a special velocity servo with interferometer feedback is used on the production disk formatters. The MAESTRO tester spin stand doesn't provide this radial head constant velocity capability. This is the principal reason that the formatting done for the demonstration of the track following servo used circular tracks. A proposed format for minimum size of the overall tracking pad is described in a later paragraph.

The 6800 disk format provides a tracking pad which is 3 Bytes long for every 60 physical bytes. This provides (765 PES samples per inner track, 1590 per outer track). For the MAESTRO tracking servo the spindle encoder was used to provide for experimental formatting. This signal provides a fixed 512 samples per revolution and a hard time base for various tracking pad sampling controls and blanking signals.

The actual overhead for tracking pads in the MAESTRO system was demonstrated to be approximately 12% (or 12 bytes out of 100). Several factors contribute to the excessive size of the tracking pad in the demonstration format and they could readily be eliminated in a design for a production device. The actual required size of the tracking pad format (after elimination of factors peculiar to the demonstration servo) is approximately 1.5 Bytes larger than that used in the 6800 14 inch disk format. This would cause an increase in the overhead for tracking pad area to about 7.5% compared to 5% used in the current 6800 format.

The most significant factor in the electronics which impacted tracking pad size was that a commercial IC designed for Winchester disk embedded servo demodulation was used to sample the playback signal and provide the position error sample output. This device, like all Winchester products, is an AC coupled circuit. In order to produce a linear error signal with this circuit, the area of the tracking pad must contain 50% mark density and 50% space or gap between offset marks. In this way the DC or mean of the signal doesn't change with mistracking. If the circuit had been constructed in a direct coupled form, the size of the overall tracking pad could have been half of the one actually demonstrated. An additional factor in choice of the "in-track" size of the tracking pad format was the tolerance in the angular location the offset marks with respect to the sync marks which are on the track centerline. This tolerance could be reduced if a "read while write" approach was used during formatting. Use of this approach would allow the 4.5 byte tracking pad described above.

Position Error Sample (PES) Demodulation

A Silicon Systems (SSI 32P544) Read Data Processor-Servo Demodulator was used to provide a differential preamp, automatic gain control and two sequential peak sample and hold circuits. The output of this circuit when properly timed sample pulses are applied yields a signal which has a range of ±0.5 track with a gain of 4 volts/track. These values are true when the write power during formatting is set to provide full track width marks. For a track pitch of 1.2 μm, a 14 milliwatt write power provided marks in the tracking pad that yielded a linear position error sample gain for the ±0.5 track range. The position error sample output from the demodulator was connected to the tracking error input of a standard Head Interface Electronics board (HIE, KODAK part number 482840).

Tracking Servo Electronics

The Head Interface Electronics (HIE) provided the required servo compensation and analog signal processing such that the servo would hold the laser read/write spot stationary during formatting and lock on to and follow the data track on the disk. The HIE is interfaced to the main control computer through a Hewlett Packard data acquisition unit and servo gains and offsets are adjustable through a graphical user interface on the computer.

Since the sample rate for demonstration was reduced by a factor of 3 compared to the standard 6800 ODR servo, the lead lag compensation circuit was adjusted accordingly. In the implementation of the tracking servo a variety of modifications were made to the HIE to allow for safe power-up conditions and provide the proper ranges for gains and offsets.

Performance of the Track Following Servo

The track following servo was demonstrated with 1.2 and 1.5 μm tracks. The closed loop tracking servo bandwidth is approximately 500 Hz (Please see Appendix B) with 35 dB of loop gain with respect to 1 μm. The loop gain is inferred in the figure in the Appendix. A loop gain of 35 dB indicates that the servo is capable of following a tracking error of 5 tracks peak-peak with 0.12 tracks peak-peak residual position error.

The averaged tracking error is also shown in Appendix B . This shows a short term playback tracking error of 1.5 tracks peak-peak with the tracking servo disabled. Appendix B also shows the tracking error with the loop closed to be approximately 0.125 tracks peak-peak.

2.3 MAESTRO II

Goals/Approach/Rationale

MAESTRO II is Kodak's dynamic optical recording test bed, for advanced recording technologies, including shorter wavelength optical heads, and high performance head support electronics. The primary purpose of this system is to provide a platform for test and integration of these technologies.

The goals set for MAESTRO II have all been achieved and/or exceeded the minimum requirements set forth in the original Statement of Work. The major objectives for MAESTRO II included: resurrecting the system to functional status, installation of a new "universal" optical recording head, software changes to allow formatting and playback of non-grooved magneto-optic media, and completion of required circuit design changes.

The approach used in upgrading the tester followed a theme of long term utility, maintaining value long after the demonstration of deliverables. This approach was high risk, as failure to complete any aspect of the modification would prevent demonstration. The reason for pursuing the high risk path was to acquire a tester that would be useful for a number of applications in the future with only minor modification. It was also evident that the resources required to complete the task at a later date may not be available.

Results

The "Lab Windows" based control software has been completed. The custom MAESTRO II system software will create a new standard for optical recording test systems control at Kodak. The system includes virtual instrument control of all test hardware, as well as fully automated testing capability of many important recording system parameters. Individual instrument states, entire test system states, and blocks of data can be saved to files and recalled at any time. Also, the data from any instrument with a front panel display can be re displayed and manipulated on the controllers' monitor, then output to a laser printer. The control system hardware includes an HP 486/66U processor, 410 MByte hard drive, National Instruments NI 488.2 interface bus controller, 16" SONY multiscan monitor, and a Kodak Ektaplus

7016PS laser printer/copier. The MAESTRO II control system is an excellent example of long term vision, and application.

Electronic designs required for support of the new universal optical head have been completed. These designs include new preamps for data and front facet detectors. The bandwidth of these preamps for both AC and DC coupled channels exceeds 45 MHz with a gain of 15,000. Other detector preamps were designed for focus, tracking and lens position sensors. In addition to new preamps, a laser driver was designed with rise and fall times of less than 3 nsec and a pulsed output current of over 300mA.

New surface mount circuit boards were designed for the front facet and data preamps as well as a new surface mount headboard for the connection interface and miscellaneous circuitry. The head electronics are in modular form and are easily separated from the head for debug or upgrade.

Modifications were also made to existing circuitry including the focus and tracking servos to accommodate the new magneto-optic formatting approach. These changes included the integration of a Head Interface Electronics (HIE) board from the 6800 product to control the magneto-optic tracking gain, sampling, and offset functions through the Multibus. Also, focus and tracking error detection circuitry were redesigned to idle while the system was recording the tracking pads and recover quickly from high write laser powers to read powers.

The new universal optical head was married to the newly designed head electronics and successfully integrated into the test system. The integration included new cabling for the headboard interface as well as characterization of system performance.

Other achievements obtained outside of the contract deliverables included successfully demonstrating the magneto-optic and write-once capabilities of the Universal optical head. A similar performance level was obtained after the MO demonstration on write-once materials. This demonstration was a landmark for Kodak optical head design leading the way to potential multi-function drives.

Results of new software, preamp designs with characterization, and sample outputs from magneto-optic and write once testing can be found in the appendix.

In summary, the Rome Laboratory HOST contract paced the development process, it is most likely that the MAESTRO II system would not have reached the current level of enhancement and robustness that has been achieved without the ambitious milestones established in the contract. A great deal has been accomplished in the past year, and as a result we have created a very useful and necessary tool for the future of optical recording at Kodak.

2.4 System Architecture

<u>System Design Concept</u>

The system concept was designed to maintain commonality with commercial hardware system developments which are currently underway at Kodak. In particular, commonality must exist with: 1) on-disk format, 2) media rotational rate, 3) in-channel data rate, 4) commercial interface protocols, and 5) potential performance growth to next generation products.

Development projects are underway at Kodak to enhance the commercial WORM KODS 6800 product line. The new WORM product family is planned to be named the System 2100. Therefore, HOST system architecture has been based on the System 2100.

<u>System 2100 Overview</u>

The System 2100 has the following specifications:

User Data Rate:	24 Mbps (3 MBytes/sec)
Data On-line:	Both sides via two heads in semi-synchronous operation
Interface:	SCSI II
Data buffer/interface speed:	6 MBytes/sec
Data Code:	(1,7) with 1.2 micron minimum mark length
Track Pitch:	1.2 micron or better
Capacity:	7 GBytes/side, 11 GBytes/disk
EDAC:	(221,205) Reed-Solomon -- capable of correcting 10-4 BER to 10-12.
MHI Data Rate/Head:	Fixed at 12 Mbits/sec (user) or 15 Mbits/sec (channel)

Advantages of System 2100 as Platform for M-O

Utilizing the System 2100 as the baseline platform for a M-O system offers the following advantages:

- M-O conversion of state-of-the-art WORM drive
- Universal head: economies of common media package and formatters
- High data rate while avoiding high MHI speed, high rpm, and high laser power
- Avoids complexity and performance waste of EQLV systems
- Double on-line capacity
- User option of independent or synchronous head operation
- More product configuration options (i.e. low cost single head entry level configuration)

2.5 System Performance

Carrier to Noise Ratio

The universal head used for the HOST contract has 61 dB CNR with a 30 Khz resolution bandwidth. Theoretical analysis shows that our new detection technology would give adequate phase margin with CNR in the low 50 dB range at 15 Mbps. Earlier versions of our data detection technology would give adequate phase margin at 61 dB CNR.

Measurements of Edge Jitter

Noise such as laser feedback, shot noise, media noise, electronics noise, etc. creates jitter, or uncertainty in the mark's edge position. Clock reference jitter is defined to be equal to the noise voltage divided by the slope at point of detection. The calculated jitter at 60 dB is 0.6615 ns. Edge-to-edge jitter was calculated to be 0.9354 ns. Excellent measurement results were obtained in the laboratory, jitter of 1.035 ns was obtained using the HOST hardware.

Bit Error Rate

Phase margin calculations show that the error rate due to edge jitter and intersymbol interference is negligible (i.e. much less that 10E-6). Our experience indicates that with such performance, the error events are dominated by media defects. The EDAC was designed with media defects in mind, in fact the EDAC was designed for an earlier generation WORM spin coated media. M-O media produced today is sputtered. It is a known fact that spin coated defects are much worse that those for sputtered media. Therefore, bit error rate calculations based on the system/media design parameters are accurate.

2.6 Summary and Conclusions

Summary

1) An M-O drive architecture was developed that is compatible with Kodak commercial plans.

2) A research-quality spin stand (MAESTRO II) was assembled that is capable of advanced systems development on M-O media.

3) A universal optical head has been designed, built, and benchmarked using M-O and WORM media.

4) Viability of pre-formatted, sampled tracking servo was demonstrated.

5) It was determined that selection of the tracking method and formatting was a primary obstacle to commercialization.

Conclusions

1) CNR is greater that 60 dB.

2) Edge jitter is approximately 1 ns. Bit window is 44 ns.

3) Edge jitter is entirely due to noise, not the media or the system.

4) Intersymbol interference is approximately 2 ns.

5) Error rate due to noise is insignificant.

6) Error rate due to media defects is correctable by EDAC.

Section 3 Requirements Verification Matrix

Performance Parameter	Goal &/or Specification	HOST Rqmt. Achieved	Verification Method: Design	Verification Method: Analysis / Simulation	Verification Method: Test	Verification Method: Similarity
System Level						
• **Data Rate**						
- Continuous (user)	25 Mbps	Y	x	x		
- Burst (user)	50 Mbps	Y	x			
• **Bit Error Rate**	1 x 10E-12	Y		x		
- Phase Margin Analysis					x	
• Carrier - to - Noise Ratio	> 60 dB		x			
Media Format						
• **Media Capacity**	5.0 GB/side, 10.0 GB total	Y	x	x		
• Track Pitch	1.5 µm		x	x	x	
• Mark Size	1.2 µm		x	x	x	
• **Durability/Reliability**	10,000 W/R/E cycles	Y	x			x
Optical Head						
• Head Efficiency	33.40%		x		x	
• Max Write/Erase Power	36nW		x		x	
• Wavelength	784 nm @ 100mW					
• Spot Size	0.71 x 0.80		x	x	x	
• Strehl Ratio	0.96		x			
• Focus Error Signal	0.323 mV/µm					
• NA	0.55		x			
• Mass	169 gm				x	
• Front Facet Monitor	0.28 V/mW					

Section 4 Future Work

4.1 Magneto-Optic Optical Head

The optical head successfully demonstrated the goals of the HOST project, yet there remains many other goals for this system. A more complete tolerancing of the head media interface will be performed in the future. This includes understanding the effects of disk tilt, head aberrations on the data and servo channels. To allow the head to test and characterize new MO media formulations we need to calibrate the liquid crystal variable retarder and data detector. This will allow the head to measure the media's phase shift and Kerr rotation. Also by characterizing the data detection system we can understand the noise contributions. This is important for further improving performance of the media.

In the 6 weeks since the HOST demonstration, we have setup the system to work with phase change on glass 14-inch media. This involved debugging the head's phase tracking system and building a write-once data channel. Examples of the system's performance are shown in Appendix E. The system showed a CNR of over 61 dB at 12 m/s. This type of performance is an early indication that we can design a high performance multifunction optical recording system.

To-date all of our experience with this head has been with glass substrate media. This is due to our past experience with high performance MO glass media. Recent modeling has indicated that with some novel electronics, a high performance coversheeted MO disk should also be possible. We also looked at the effect of a coversheet on the MO disk and calculated this would cause a CNR drop of approximately 3 dB for typical coversheet birefringence. Preliminary measurements show quantitative agreement with this amount of CNR degradation. We have breadboarded and bench tested the birefringence compensation electronics. The results indicate that the CNR drop can be limited to less than 1 dB. This would allow inexpensive MO disks to be manufactured with much of the same equipment that produces our commercial 14-inch PC/Al coversheeted disk. It would also allow use of current hubs, cartridges, robotics, etc. and make a true multifunction library feasible. To demonstrate the head's performance with the coversheeted MO media, we need to change focus/tracking detector and install birefringence cancellation electronics. A new focus tracking detector that is not sensitive to media su[illegible]rate birefringence is currently being prototyped. The change in the focus tracking detector is also required to demonstrate performance on All EK Media (MO TbFeCo on glass, WHO phase change on glass, coversheeted MO media on aluminum, coversheeted WHO phase change media, CD-WHO media).

4.2 Improved Formatting Method

In the commercial WORM media, the tracking pads consist of lone marks which at 800 nanoseconds duration are the longest written marks on the disk. Unwritten leading and trailing zones of one byte in length provides for ample mismatch between the phase of the read and write clocks. The format of a minimum size tracking pad is illustrated in Figure 4.2-1. The first mark in the tracking pad formed by the beginning of the pair of offset marks is an identifier. The identifier is a mark that is 2 channel bits long and begins the read back sample timing sequence. Since the offset marks overlap in the in-track direction the read signal persists for the entire length of the composite mark. This provides a read signal that is uniquely identifiable when compared with the encoded data, since it exceeds the maximum mark length of four channel bits. The composite identifier is followed by a four bit space on the Type B tracking pad (offset 1/2 track, outward from the nominal track center). A short distance after the Type B mark resumes the Type A mark ends.

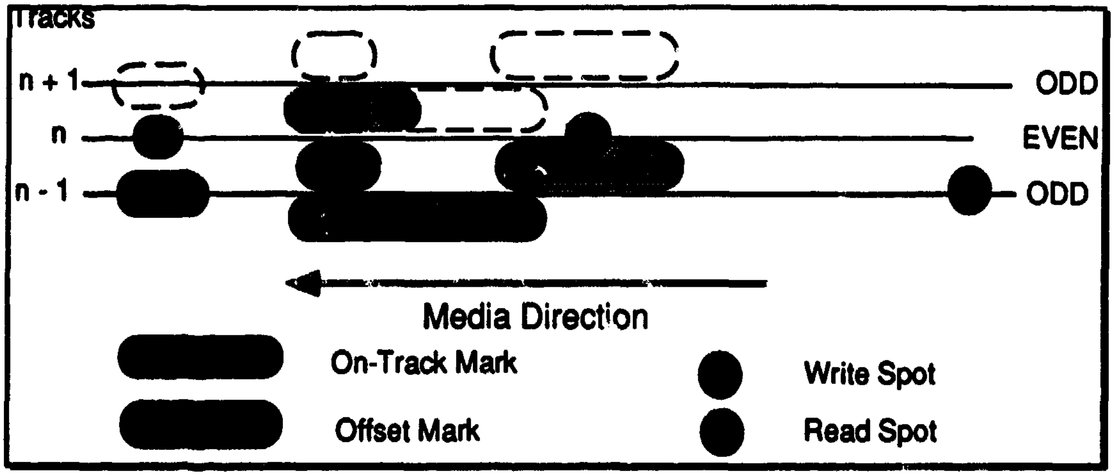


Figure 4.2-1: Tracking Pad details

In the disk read back system the read spot signal of the data channel would be sampled two bit cells after the onset of the identifier area and averaged for four bit cells duration. It would be sampled again beginning at 6 bit cells in and averaged again for four bit cells. The two samples are then made available to the tracking servo system as the A and B tracking error signals. From that point in the servo system and beyond, the A and B tracking error signals would be handled in the same way as in the commercial WORM system. The modulation of the A and B tracking error signals in the M-O media system should be greater than that of the current KODS 6800 system and differencing the A and B signals should provide improved rejection of common mode signals compared to the KODS system. Note that unlike the WORM tracking error signal which repeats at one cycle for every track, the magneto-optic media formatted with the proposed offset alternating tracking pad scheme would provide a tracking error signal which repeats every two tracks and should remain continuously detectable when moving across tracks. Since the tracking error signal slope reverses when going more than $1/2$ track off center, the servo system will automatically reject locking on to an adjacent odd track when it is looking for an even track, thereby improving tracking integrity.

In order to format these offset alternating tracking pads the formatting machine must be capable of writing marks at half the track spacing that is currently required. Rather than moving the writing head at $1/2$ speed in the radial direction a special multi-spot head would enable writing the offset alternating tracking pads. Writing the offset alternating tracking pads requires accurate registration locally from track to track. This could be accomplished using one spot which is centered over the previously written track to provide the trigger signal for writing the outer offset mark one full track away. This means that the write spot from the multi-spot head is actually 1.5 tracks away from the read spot which triggered it. The duty cycle of the offset mark writing laser will be alternated as required for writing a Type A tracking pad or a Type B tracking pad.

The existing servo writer radial access positioning system which moves the head is controlled by use of a fringe counting interferometric system. Its positional accuracy is fully capable of meeting the track-to-track accuracy required.

4.3 MAESTRO II

Various optical recording technologies can be broken down into subsystems including record and playback channels, focus and tracking servo systems, and optical heads. MAESTRO II is in a process of continuing evolution and improvement toward a goal of complete modularity of electronic, optical, and software subsystems.

The software continues to evolve for storing and recalling instrument test setups and automated tests will continue to meet constantly changing needs. An "on line" comprehensive documentation package of all software is currently being written.

The current MAESTRO II design objective is to continue in the creation of a flexible system capable of changing "plug-in" subsystem modules with minimum down time. This will allow for maximum flexibility in adding new heads or support electronics. Some less obvious advantages are the ability to use various read channels or servo electronics with the same head, possibly in the evaluation of different recording material systems. Changing the wavelength of an optical head will present its own unique set of systems requirements that must be accounted for in this flexible system architecture. This will ensure an efficient, low cost transition to any wavelength or material system when required, with maximum flexibility once installed.

Appendices

Appendix A Optical Head

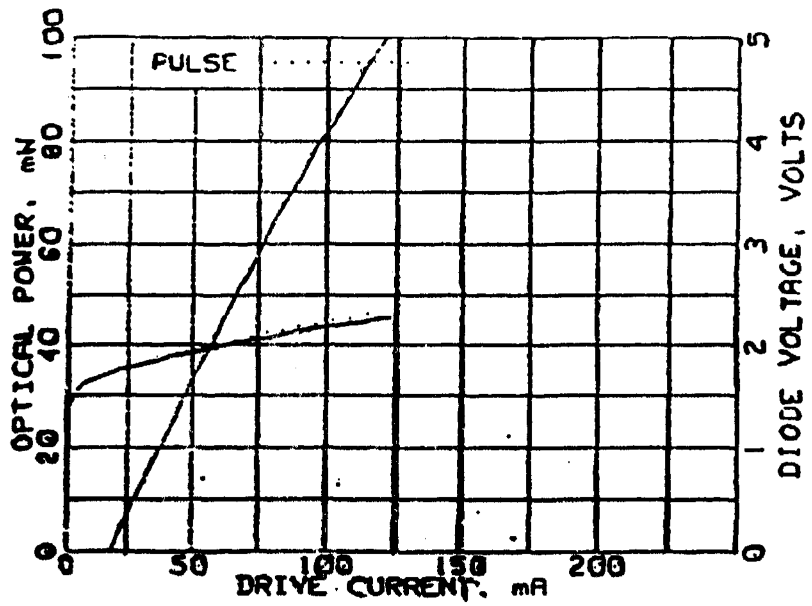
Figure A-1 SDL Laser Specification

SPECTRA DIODE LABS. INC.

DEVICE TYPE: SDL-5411-G1 SERIAL NUMBER: MV919
DATE: 05 DECEMBER 1992 TIME: 10:39

PARAMETER	PULSED	CW	UNITS
THRESHOLD	17	18	mA
DIFF. Q.E.	64	62	%
SLOPE EFF	1.01	.98	W/A
V AT 100 mA	2.25	2.19	VOLTS
RESISTANCE	9.30	4.84	OHMS
I AT 100 mW	118	120	mA

TEST TEMPERATURE: 25 DEG. C
PULSE: WIDTH = 200NSAC. RATE = 10IHz
WAVELENGTH: 784 nm
MONITOR GAIN: 1.3 uA/mW



•••••••••• SHIPMENT CHECKLIST CHECKED BY
LABELS: SDL, S/N ✓, : -3009 (31 : ✓, : -3052
SERIAL NUMBERS MATCH ✓ WAVELENGTH MATCHES ORDER ✓
OPERATOR'S MANUAL ✓ SOCKET ✓ HEATSINK NA

Figure A-2 Laser Noise Measurements

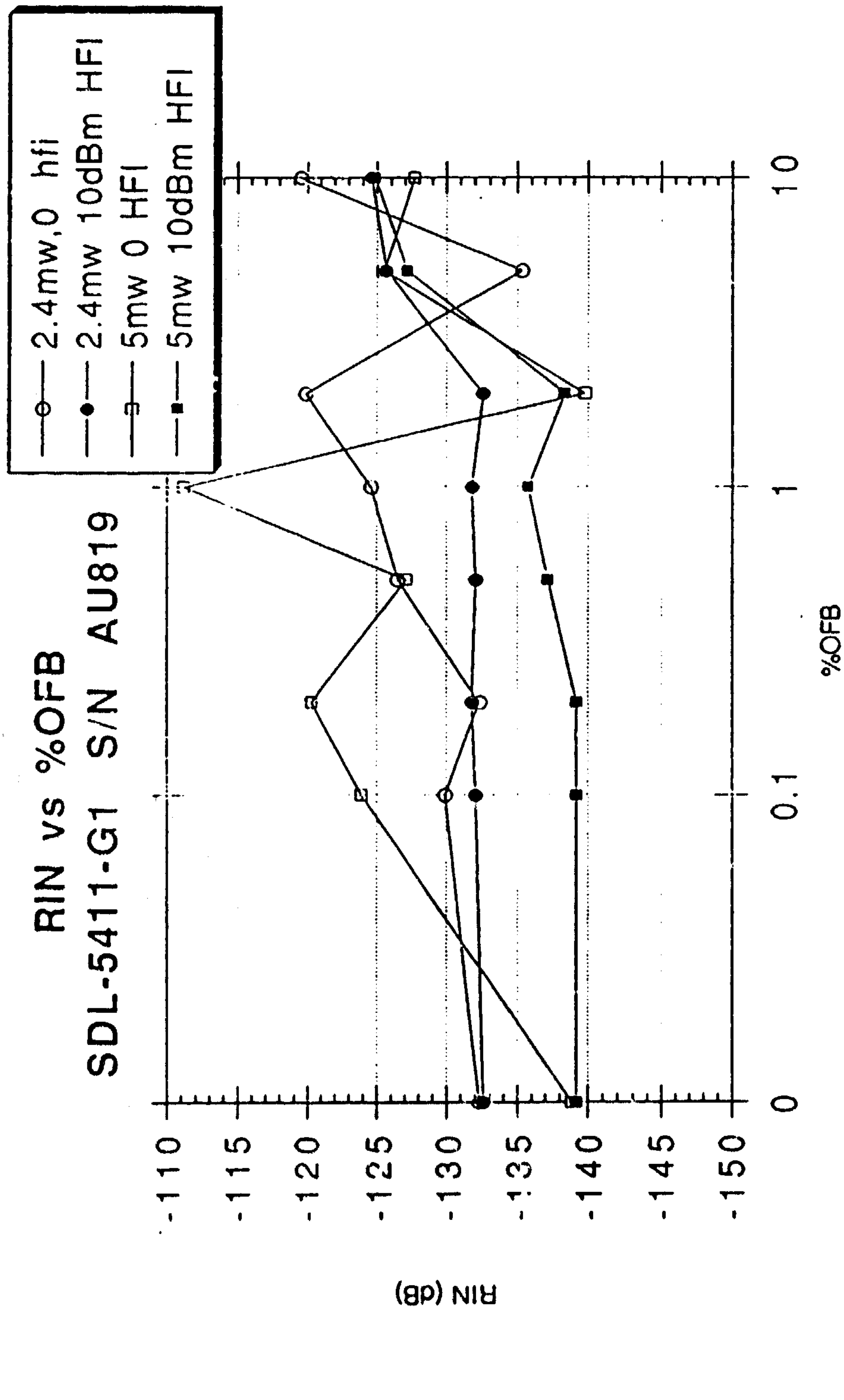
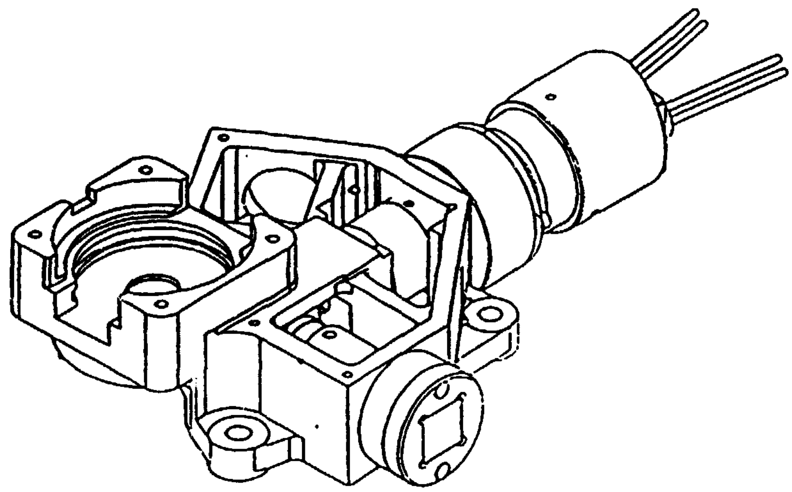
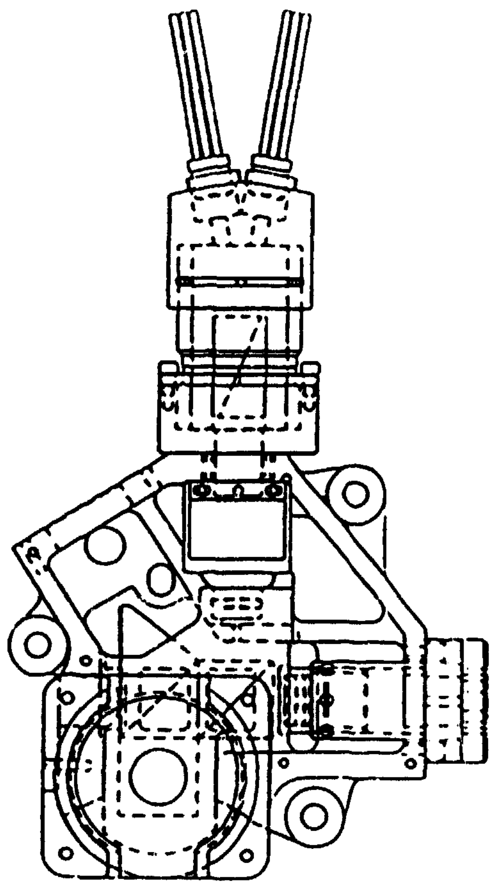


Figure A-3 Mechanical Drawings



FULL SIZE



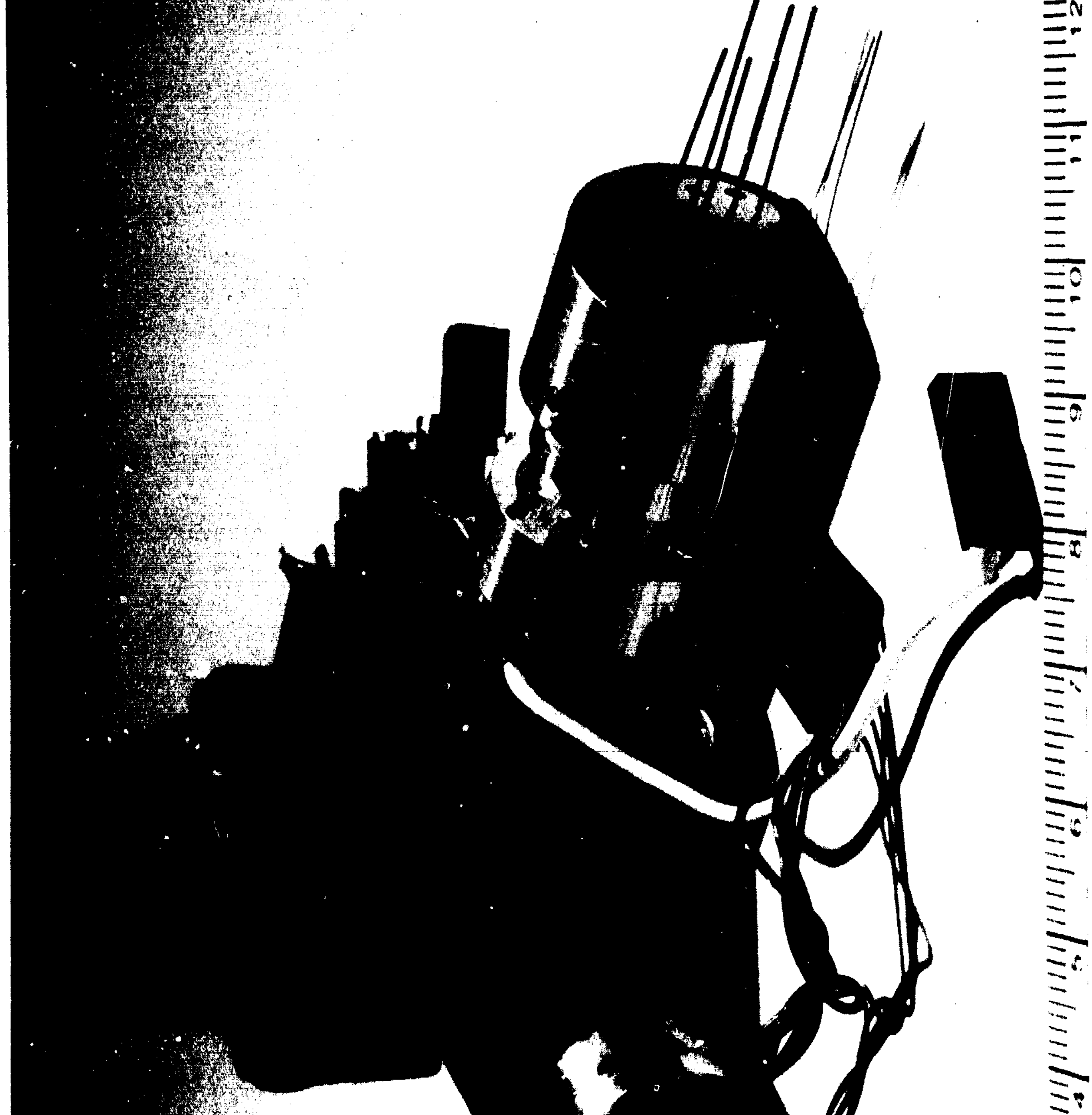


Figure A-4 Photograph of Universal Optical Head

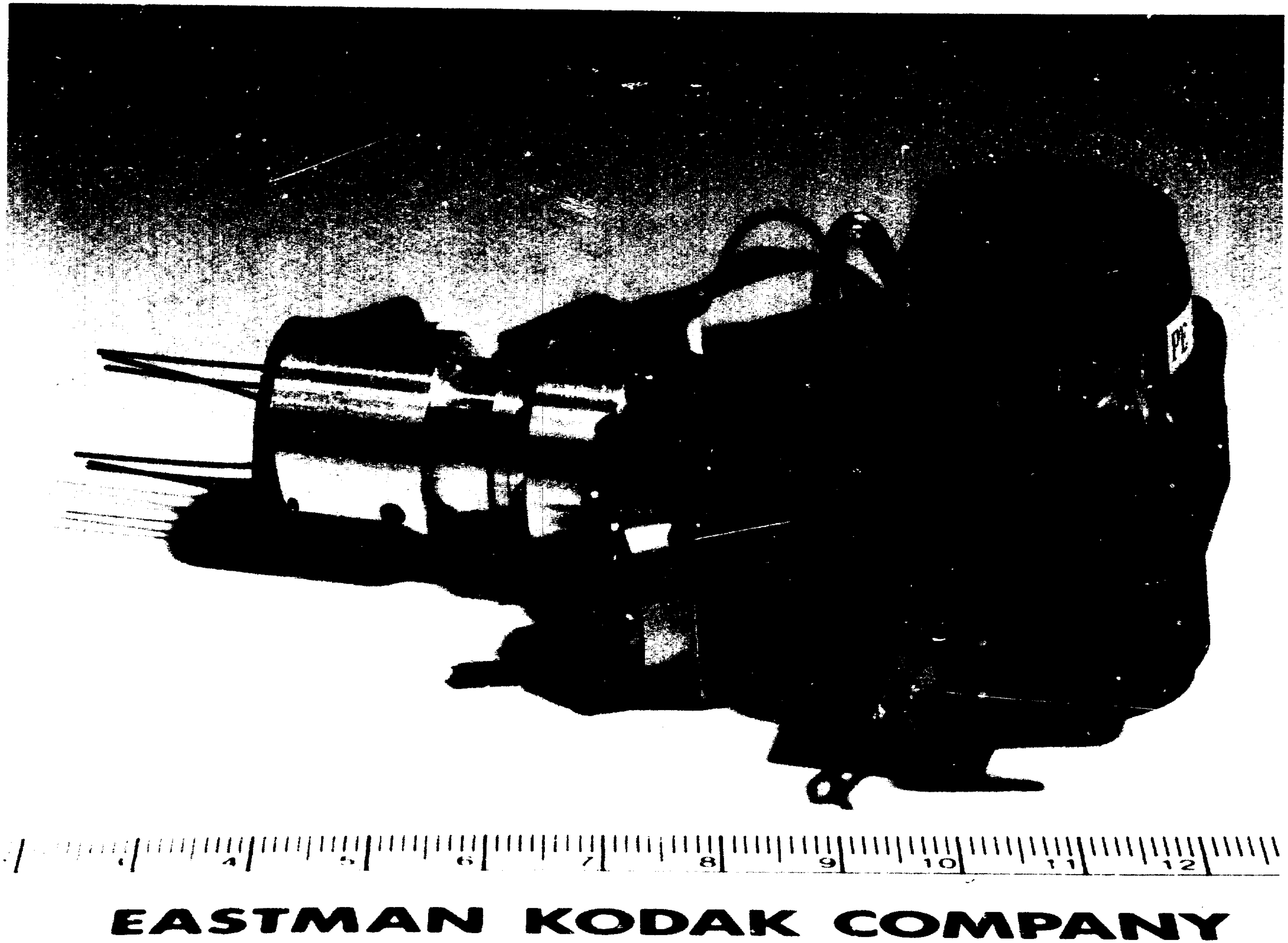


Figure A-5 Photograph of Universal Optical Head

Figure A-6 LCVR Measurements

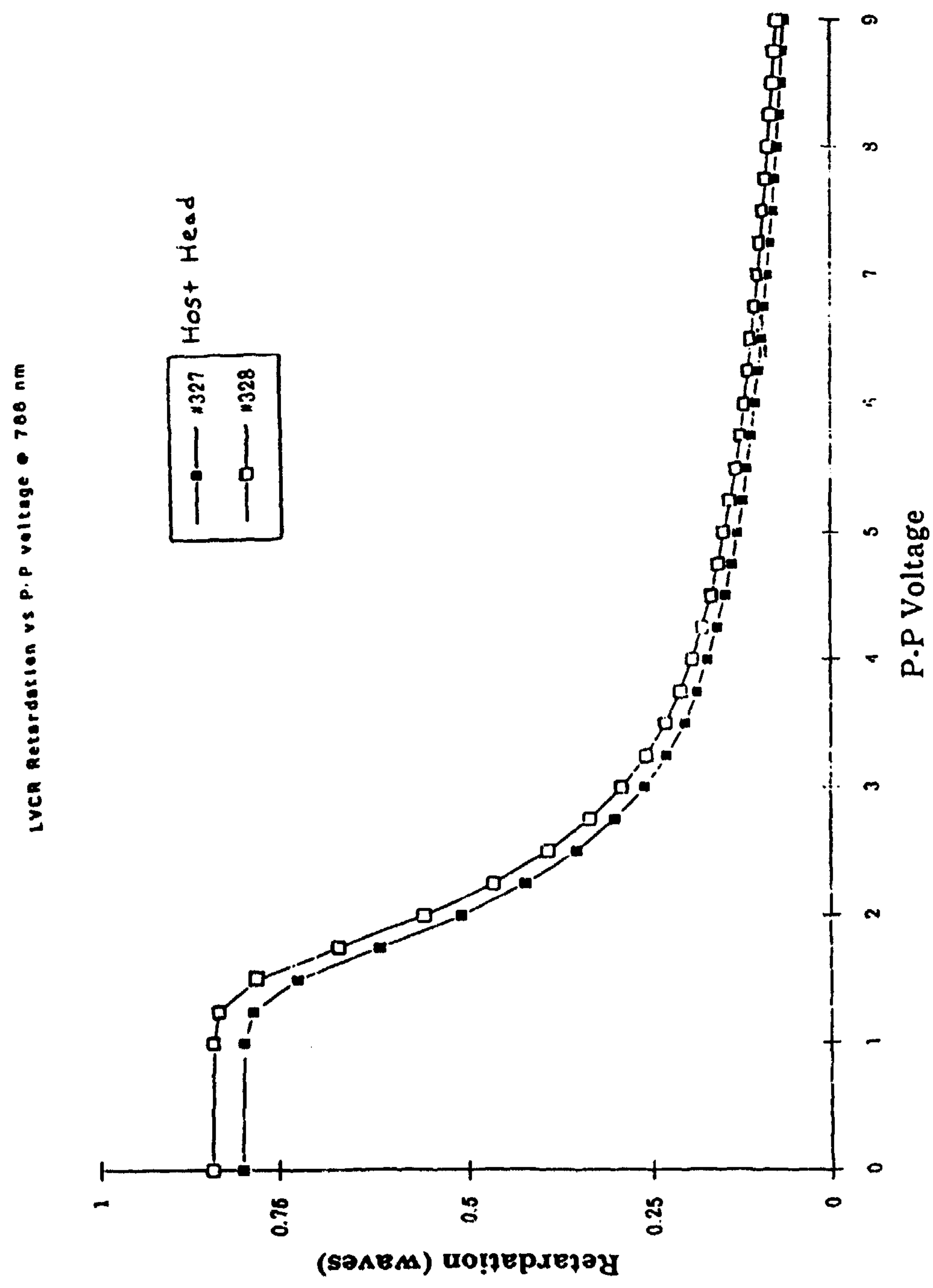


Figure A-7 Collimator Specification

A-375 MOLDED GLASS COLLIMATOR

A-375 is a single-element molded from high-index glass using the Kodak Precision Glass Molding process. While designed for near-infrared wavelength laser diodes, this collimator is also suitable for visible diode applications. A 0.275 mm BK-7 window has been incorporated into the design. Purchase options: lens, lens centered, lens centered and coated.

Focal length (mm):	7.5
Numerical aperture:	.30
Beam diameter (mm):	4.5
Axial wavefront distortion: at 670 nm (waves, rms)	<0.15
Surface Quality:	60 - 40

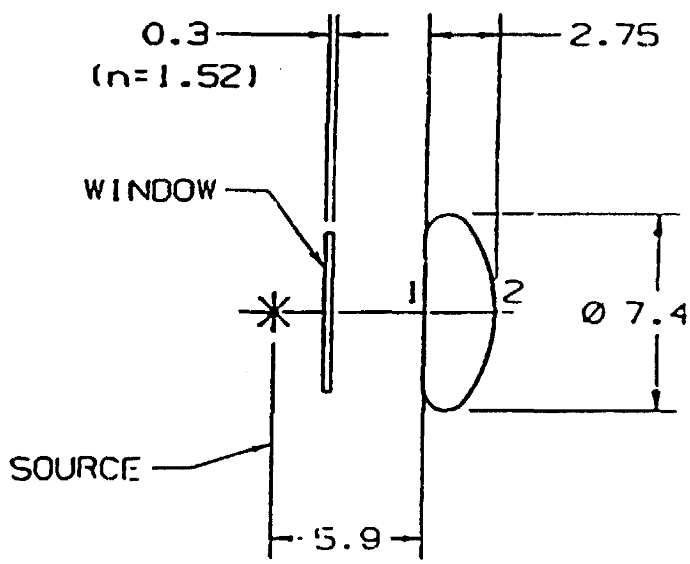
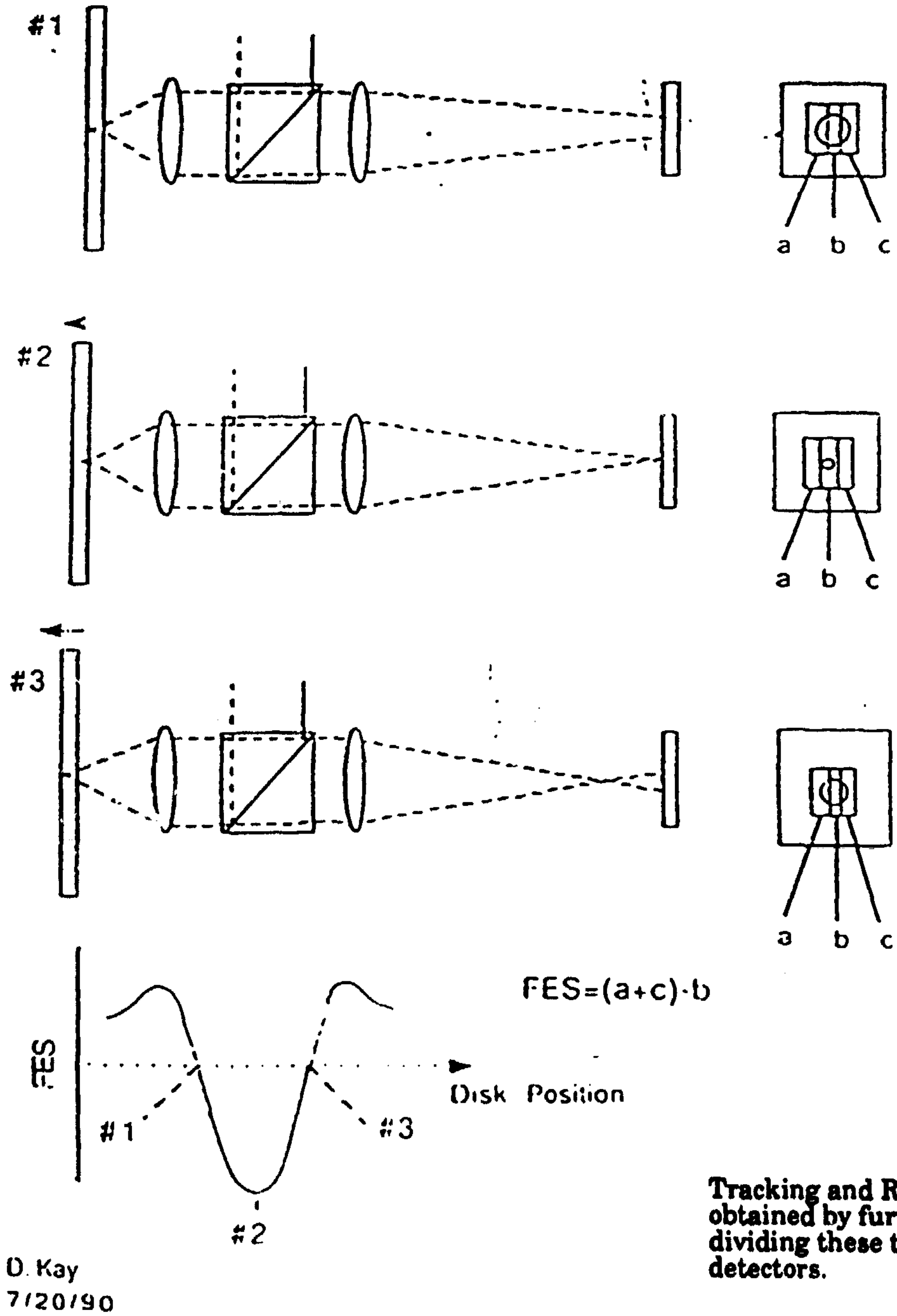
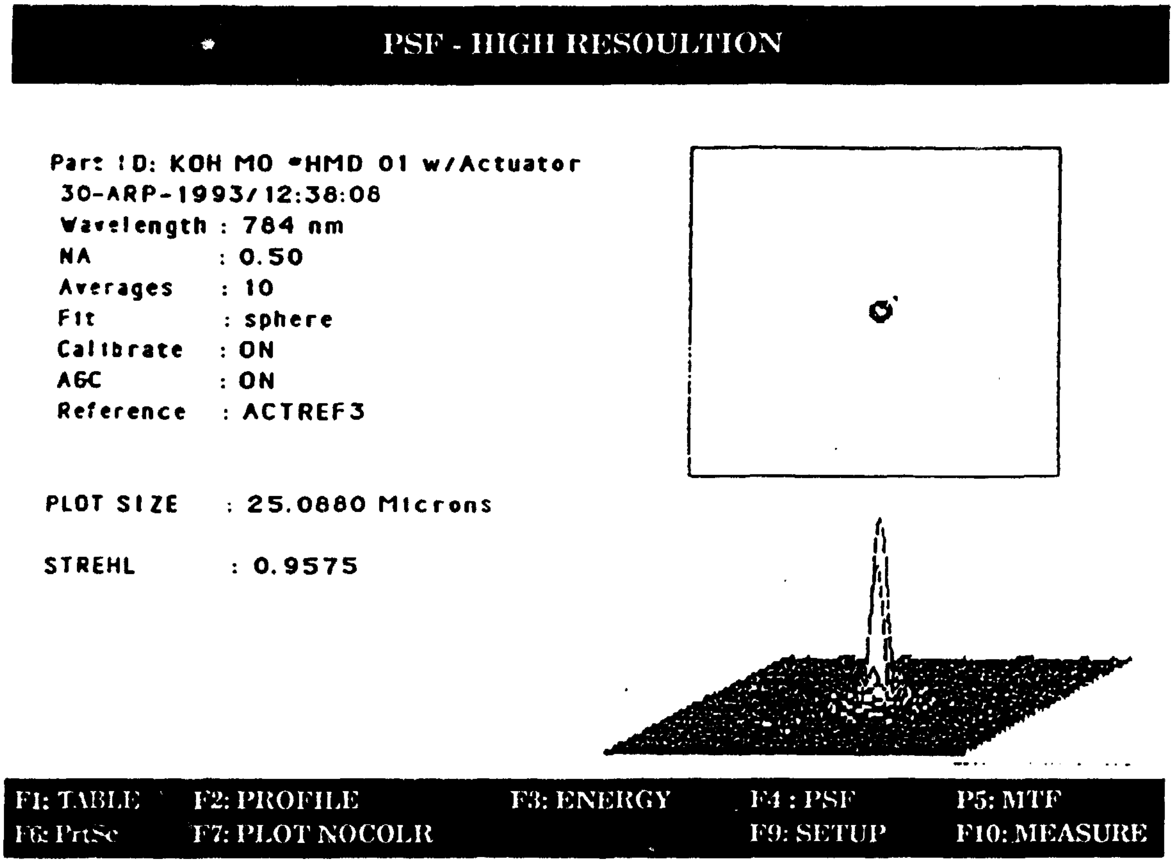


Figure A-8 Spot Size Focus Sensor



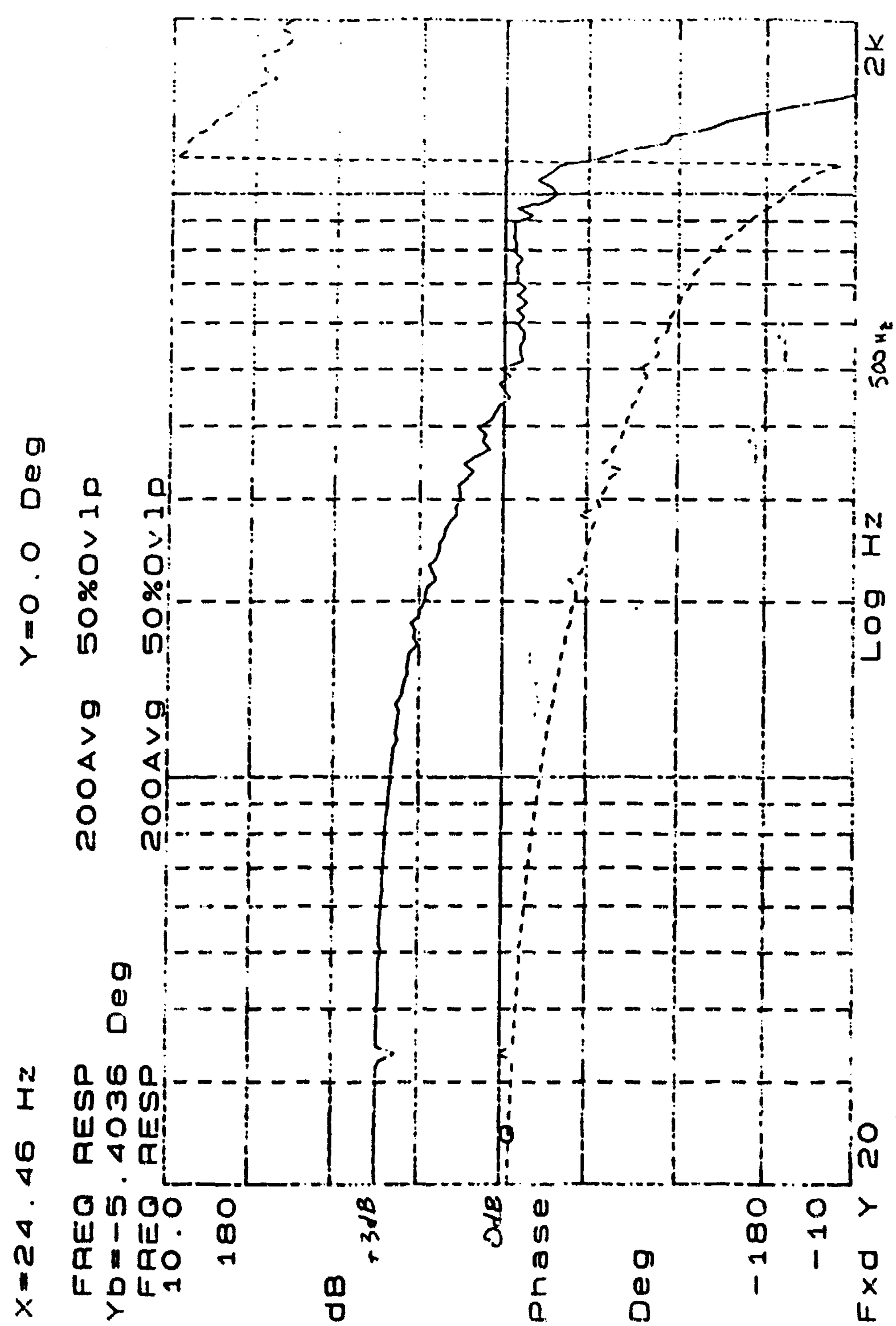
Tracking and RF can be obtained by further sub-dividing these three detectors.

Figure A-9 Optical Spot Quality Measurement



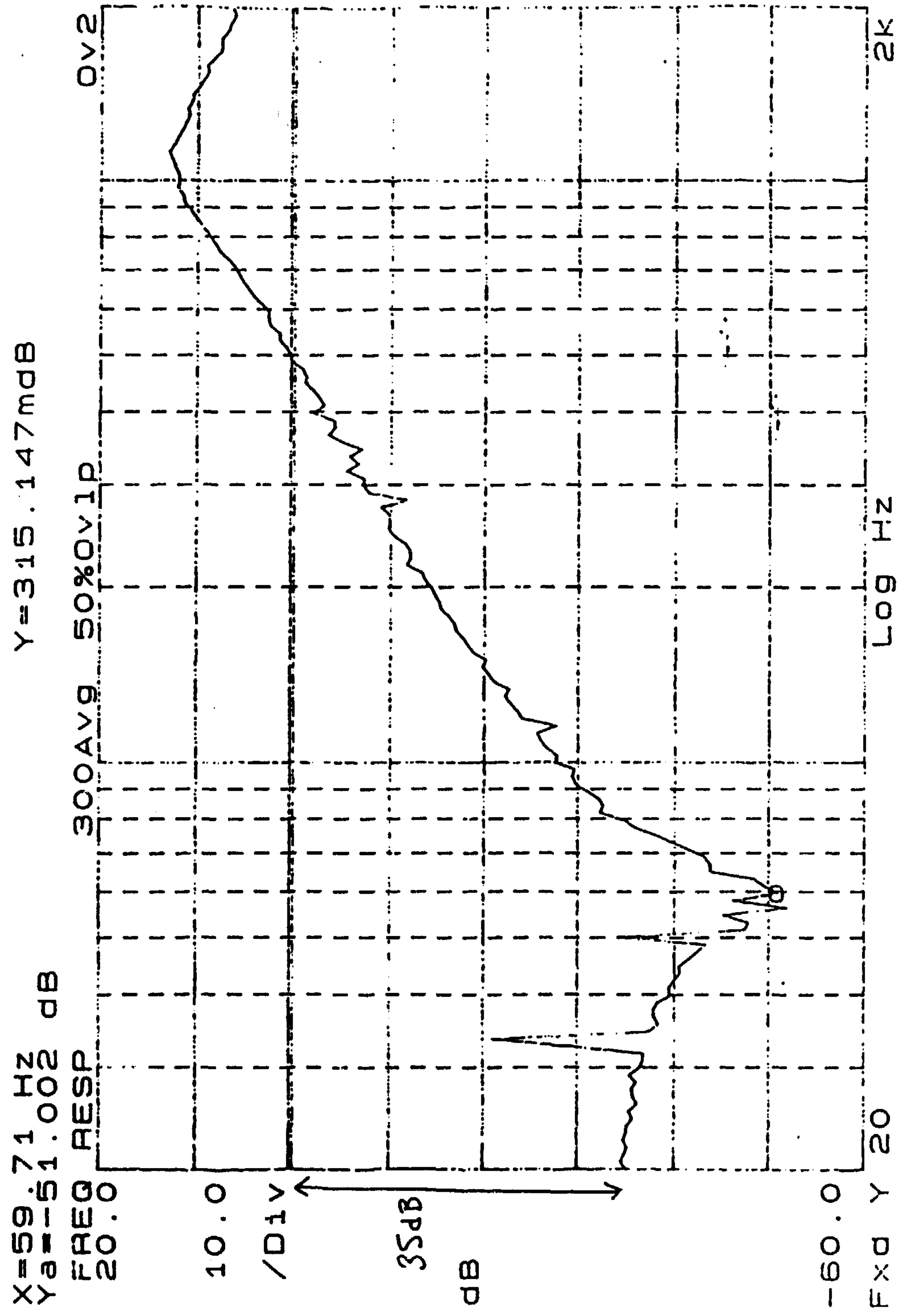
Appendix B Track Following Servo

Figure B-1 Closed Loop Transfer Function



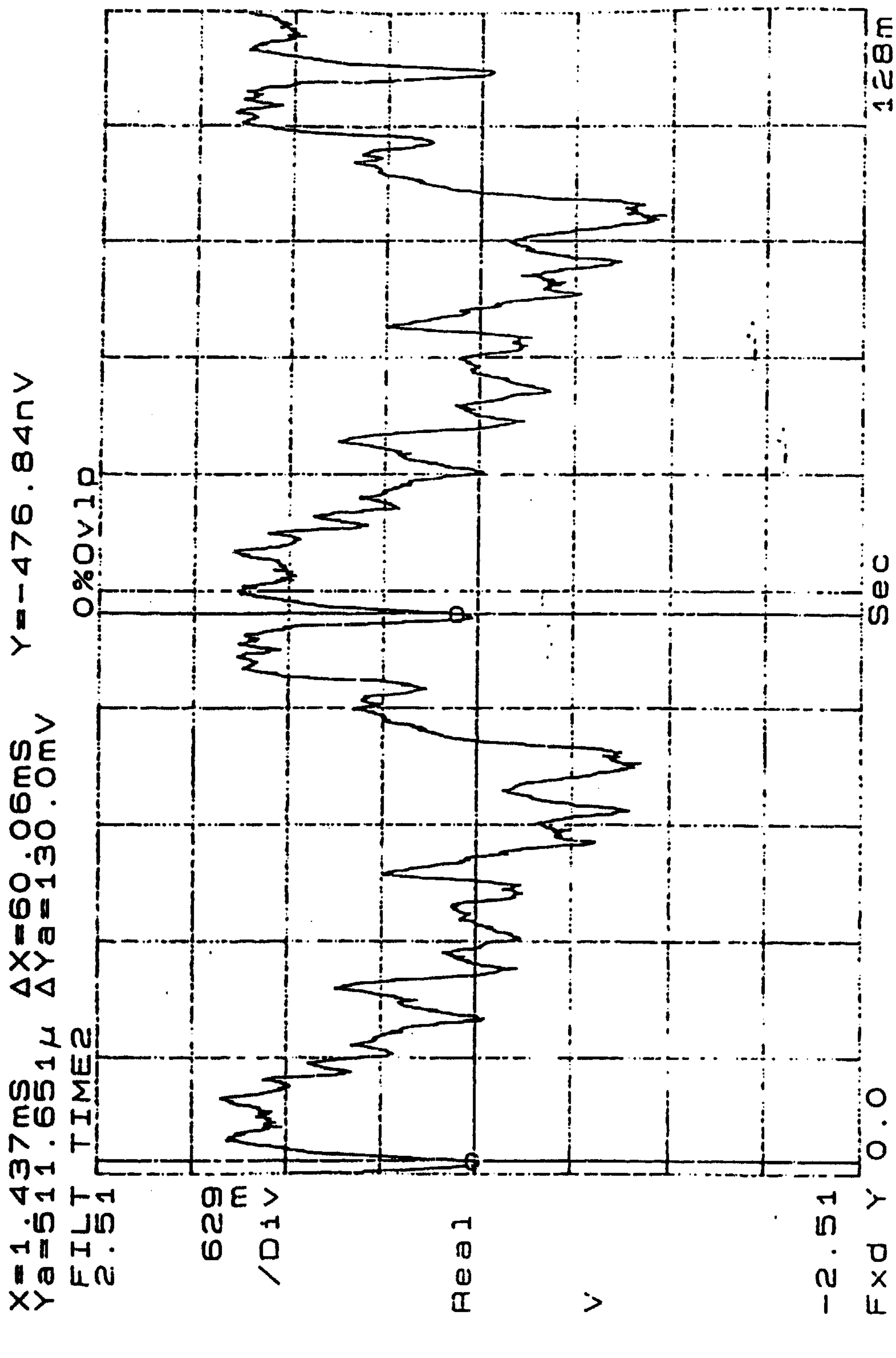
Closed Loop Transfer Function, Tracking Servo

Figure B-2 Closed Loop Error Command



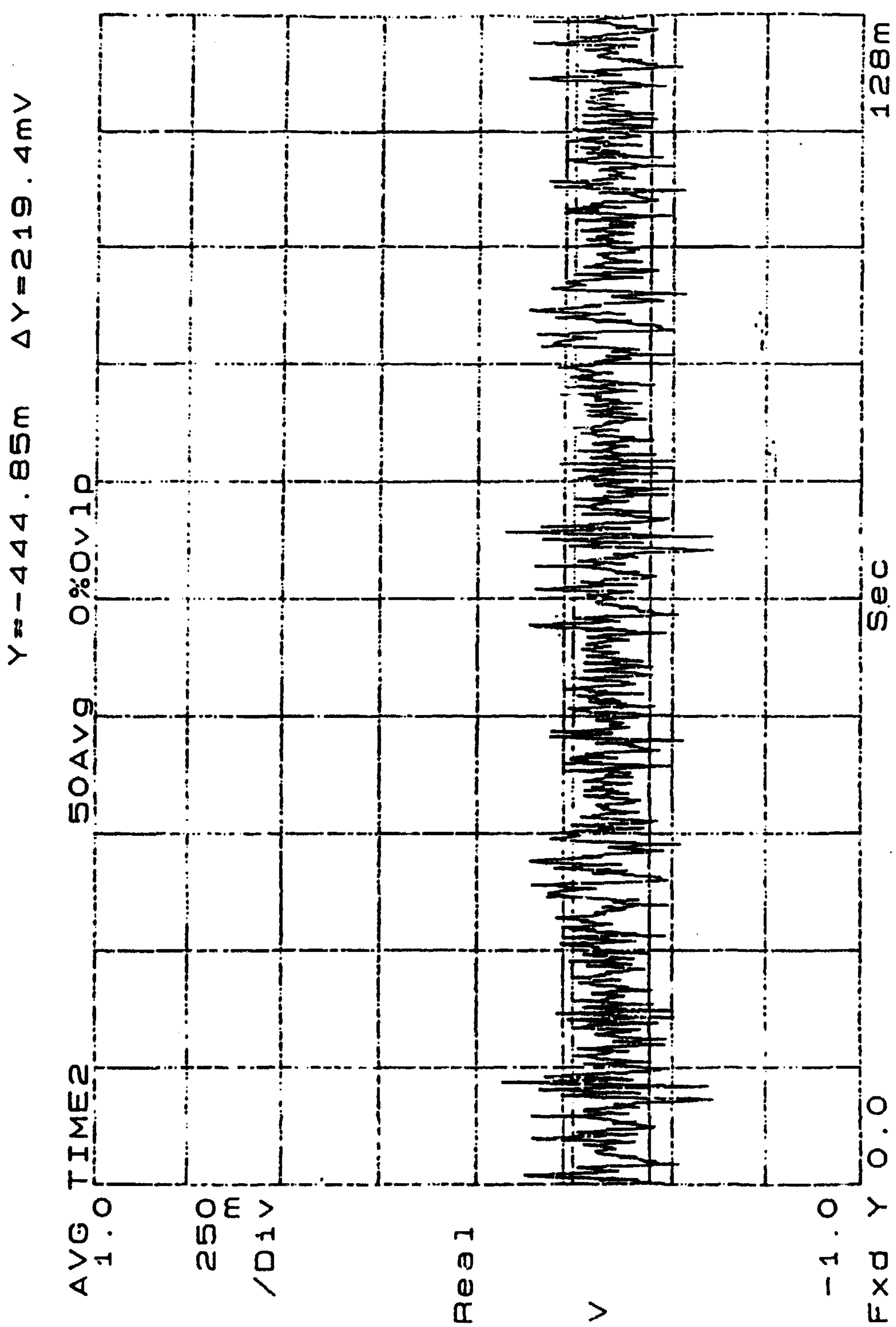
Closed Loop Error to Command, Tracking Servo

Figure B-3 Time Averaged Tracking Error, Tracking Servo "Off"



Time Average Tracking Error, Tracking Servo = OFF
Test Point Scale = 4 volts/1 track
Plot scale = .15 tracks/division

Figure B-4 Time Averaged Tracking Error, Tracking Servo "On"



Time Averaged Tracking Error, Tracking Servo = ON
Testing Point Scale = 4 volts/track
Plot Scale = .063 tracks/division

Appendix C MAESTRO II

Figure C-1 MAESTRO II Block Diagram

MAESTRO II EVALUATION SPIN STAND

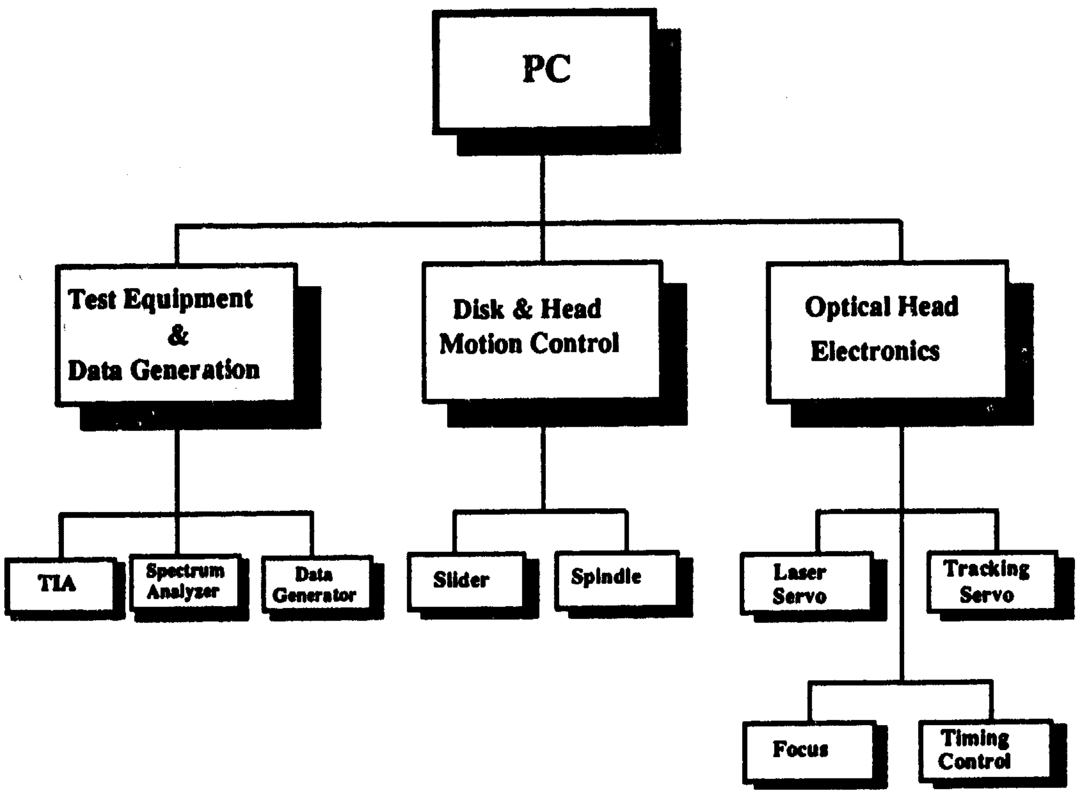


Figure C-2 Head Electronics Boards

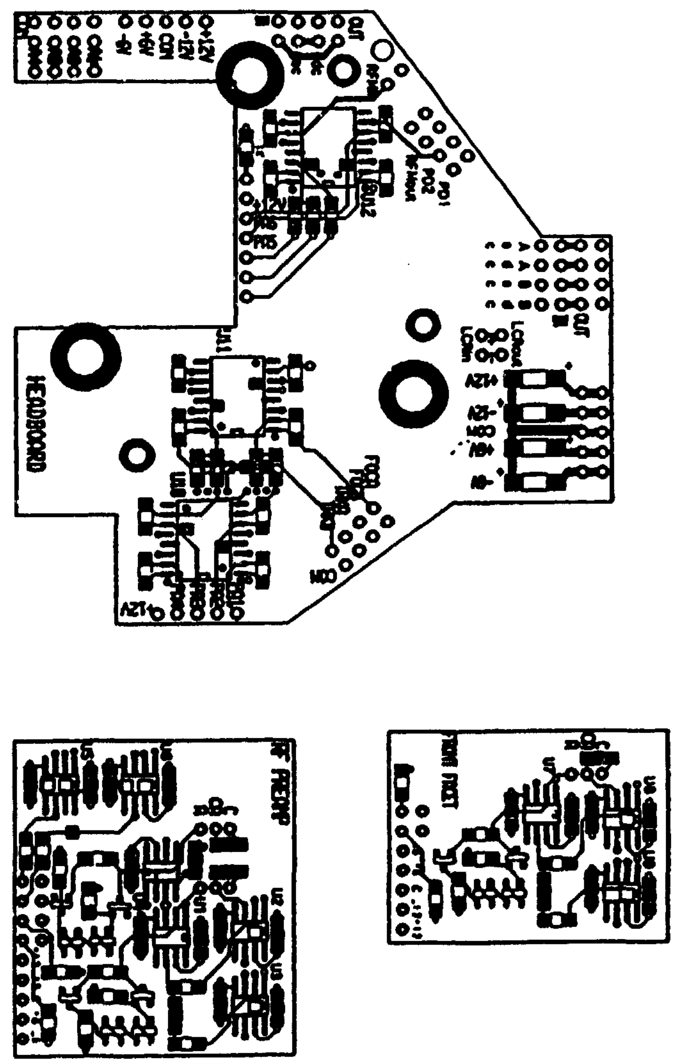


Figure C-3 Radial Position Sensor Schematics

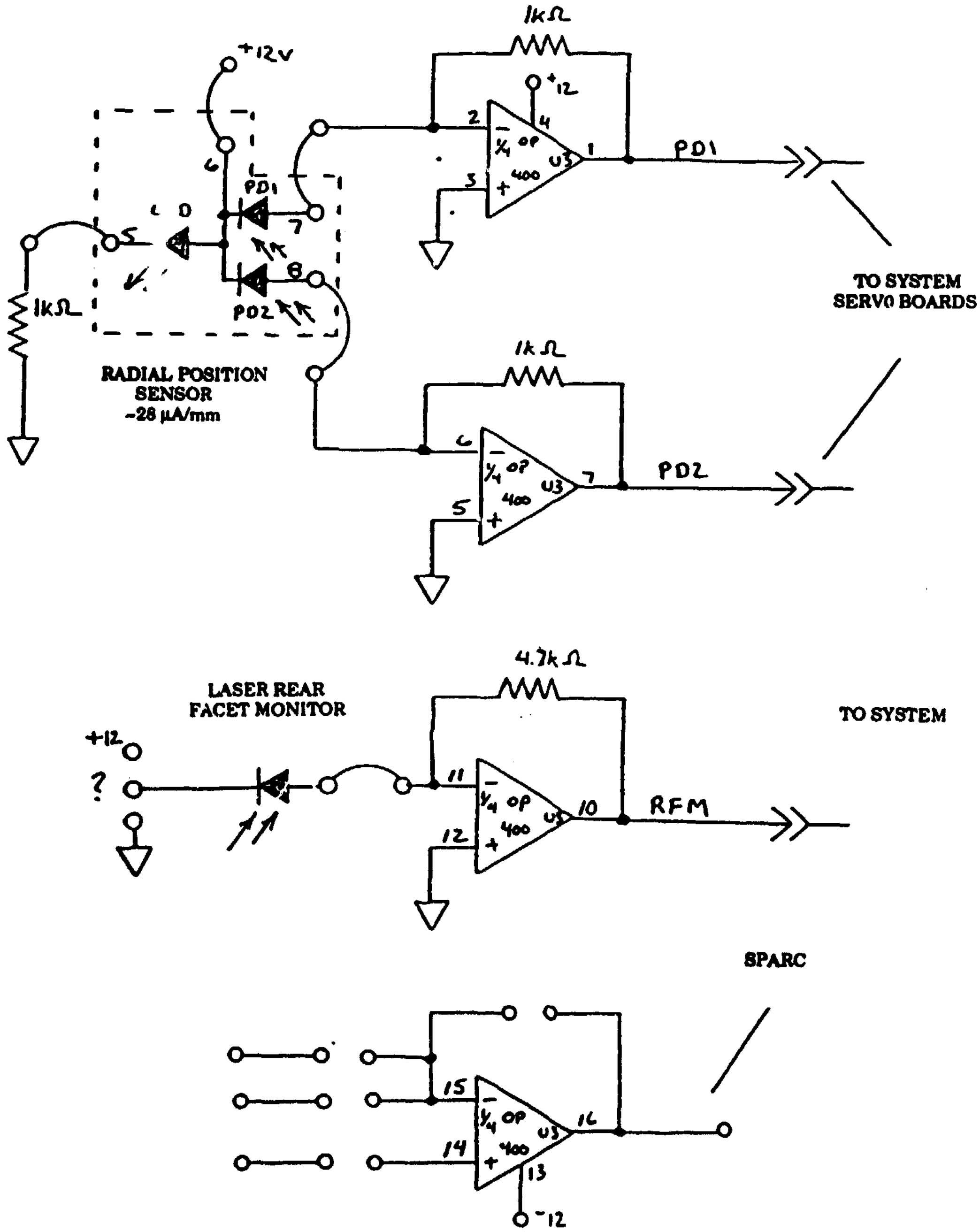


Figure C-4 Focus & Tracking Pre-amp Summing

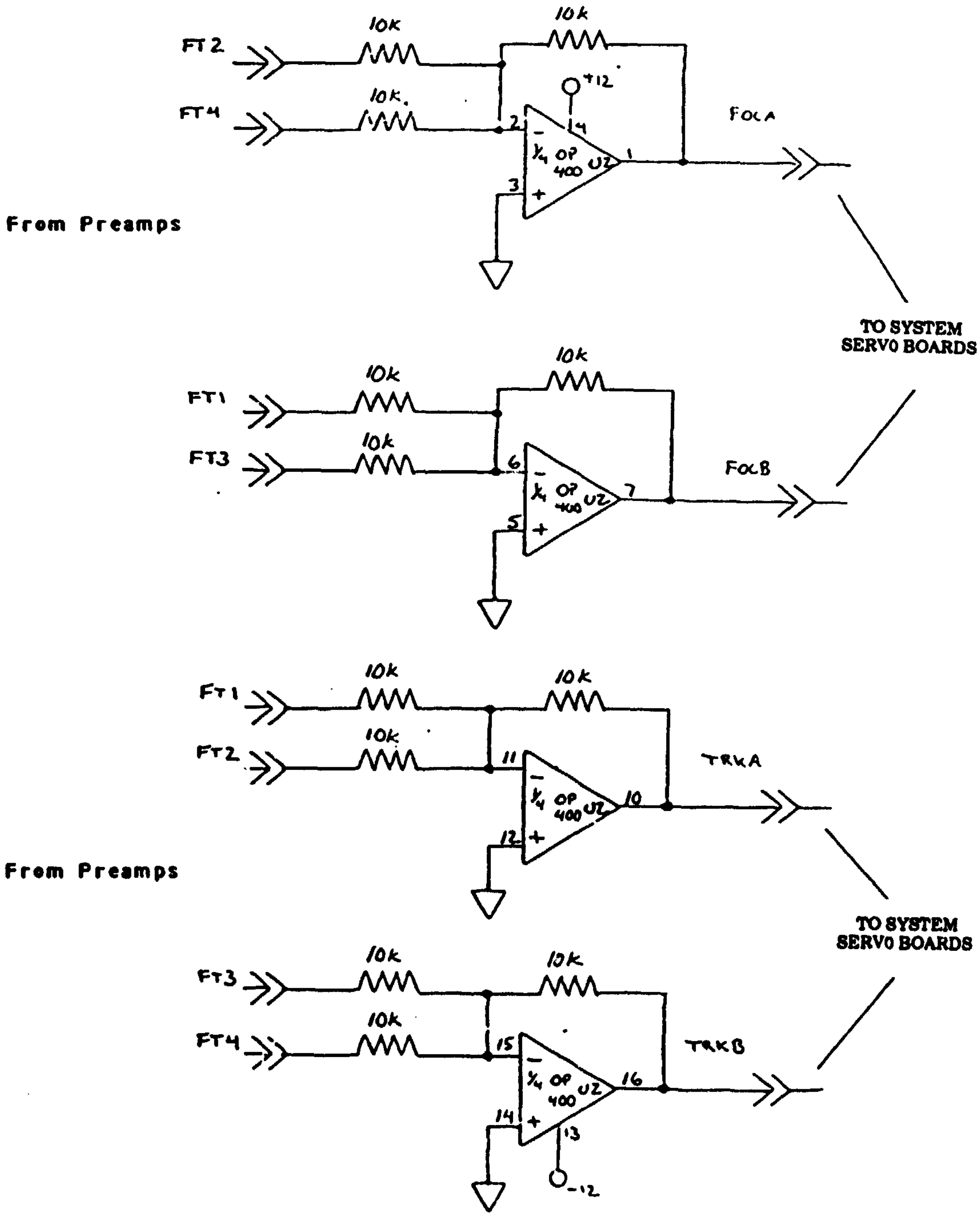
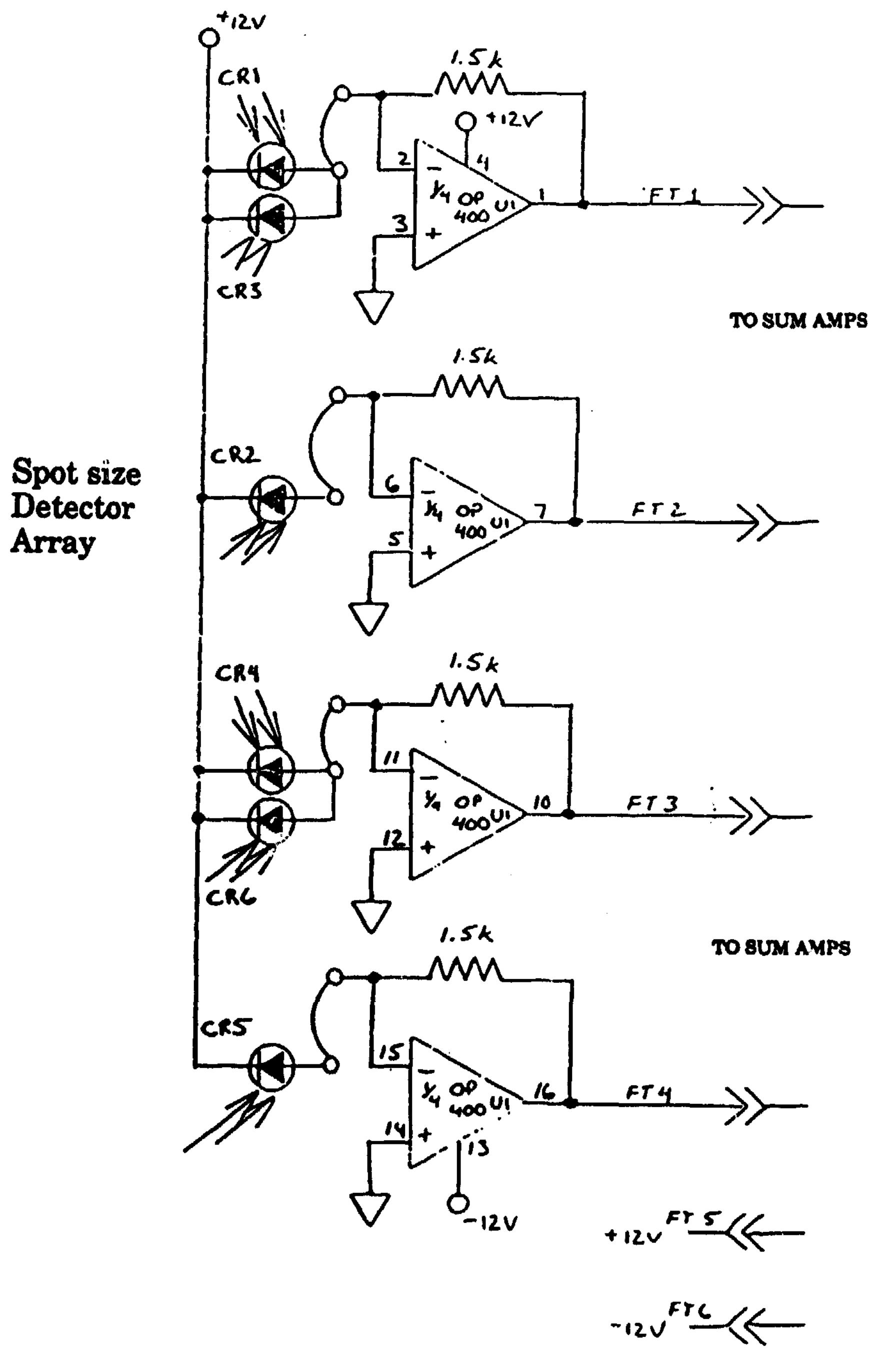
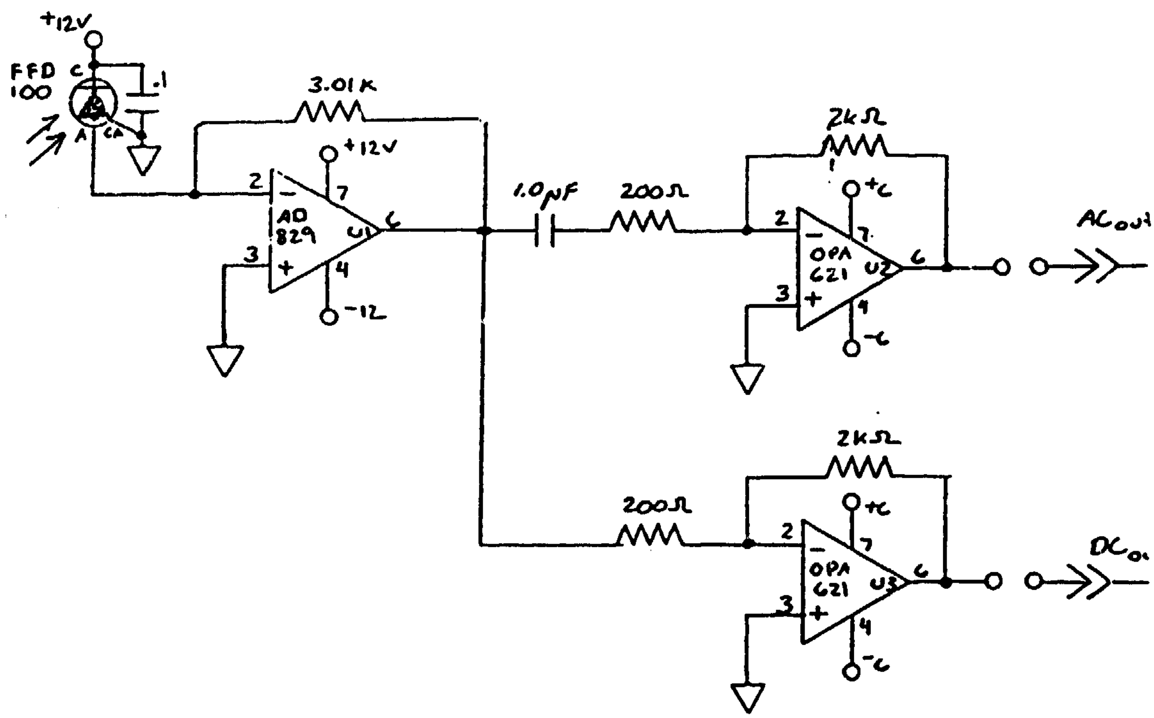


Figure C-5   Focus & Tracking Pre-amp



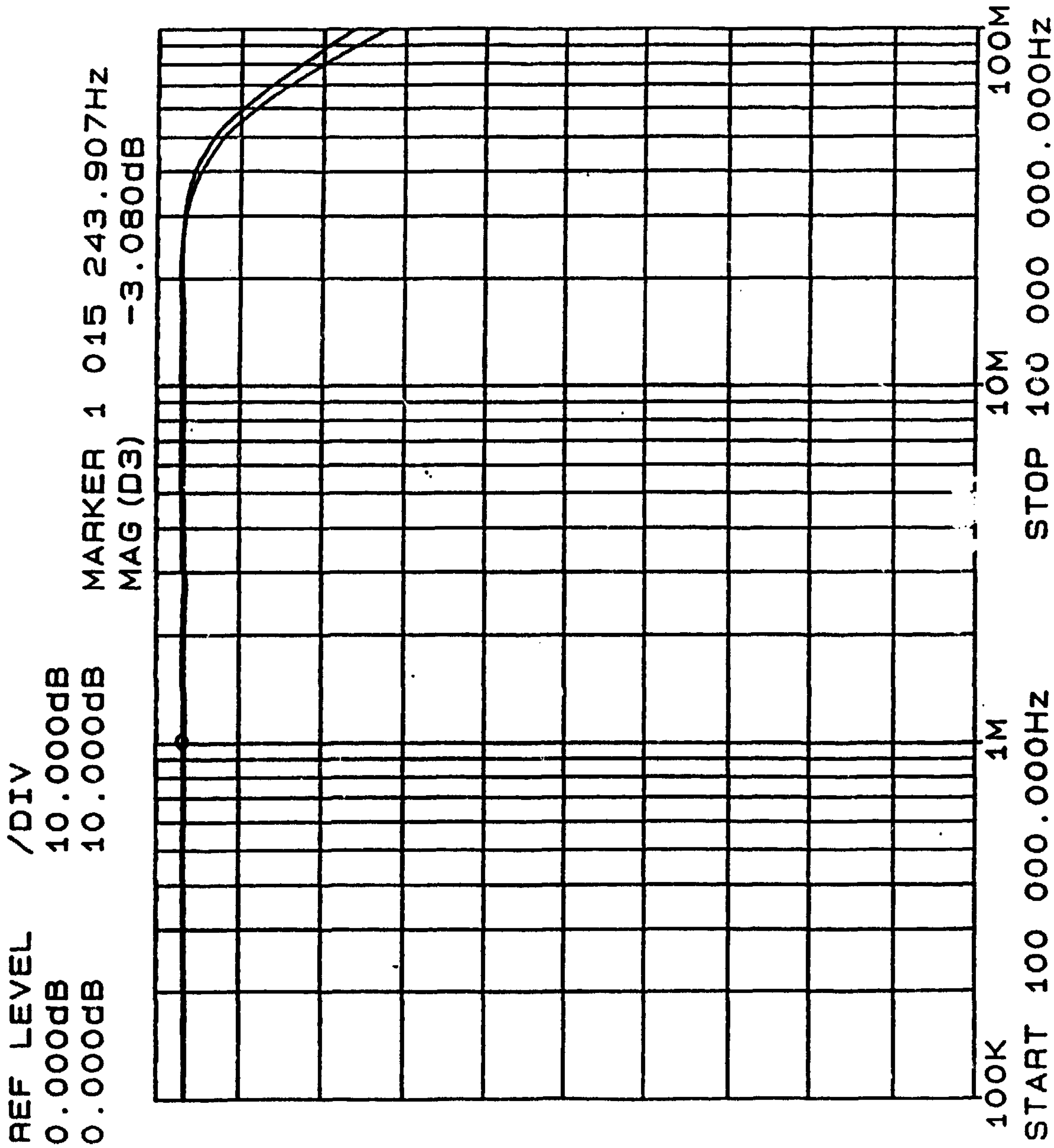
Steve Dohmeier
3/24/93

Figure C-6 RF & Front Facet Pre-amp



* **Front facet uses only 1 preamp.**
RF board requires 2 preamps.

Figure C-7 Spectrum of RF Bandwidth



Appendix D System Architecture

Figure D-1 System Architecture Parameters

Created: M. Meichle
06/28/93

Minimum Mark=1.2 um
User Data Rate= 12 Mbit/sec
Channel Data Rate= 14.87 Mbit/sec
User Bytes/Sector=1024 bytes
Channel Bytes/sector=1269 Bytes
Track Pitch= 1.5 um
Channel Bit= 44.833 nS (11.152 MHz)
Capacity/side= 5.53 GBytes
Capacity/disk=11.06 GBytes

Band	Inner Radiu	Outer Radius	RPM	Sec/Re	Min Vel	Max Vel	Tracks/ Band	User MBytes/ Track	User MBytes/ Band
0	70	91	1825.8	0.0329	13.38	17.40	14000	0.0493	690.1
1	91	112	1404.5	0.0427	13.38	16.47	14000	0.0641	897.1
2	112	133	1141.1	0.0526	13.38	15.89	14000	0.0789	1104.2
3	133	154	961.0	0.0624	13.38	15.50	14000	0.0937	1311.2
4	154	175	829.9	0.0723	13.38	15.21	14000	0.1084	1528.2
								GBytes/Side=	5.5308

Test Conditions: (adjust accordingly to radius)

eg:

130 mm @ 1000 rpm = (1000 rpm)*2*pi*(130 mm)/(60*1000)=13.614 m/s

time/min mark= 1000*1.2 um/13.614 m/s = 88.145 nS

channel bit=min mark time/2 = 88.145 nS/2 = 44.072 nS

Figure D-2 Feasibility of the Head-Media Interface (HMI)

Feasibility Demonstration of the Head/Media Interface

Review:

Two Head at 15 Mbits/second (channel)

Disk Capacity of 11 GBytes (user)

Track Pitch: 1.5 um

Modulation Code: (1,7), rate 2/3, 44.843 nS channel bit duration

Worst Case Recording Conditions occur at 13.4 m/s

Erase (-25 to 30 dB)

Error rate correctable to 10^{-12}

Reliable system, realistic system tolerance

Figure D-3 System 2100 Specifications

SYSTEM 2100

* New WORM drive product family

* MO conversion was basis for the HCOJ proposal

* System 2100 specifications have improved since the HCOJ proposal (conversion to (1,7) code)

  * Quantized Constant Linear Velocity (RPM changes between bands)

  * Two Heads, one on each side, semi-synchronous data transfer

  * Fixed Data Rate: 3 MBytes/sec (1.5 MBytes/sec each head)

  * Enhanced capacity: (new code (1,7), new detection method, shorter mark lengths, possible wavelength change to 690 nm) (14 - 18 GByte WORM, 11 - 15 GByte MO)

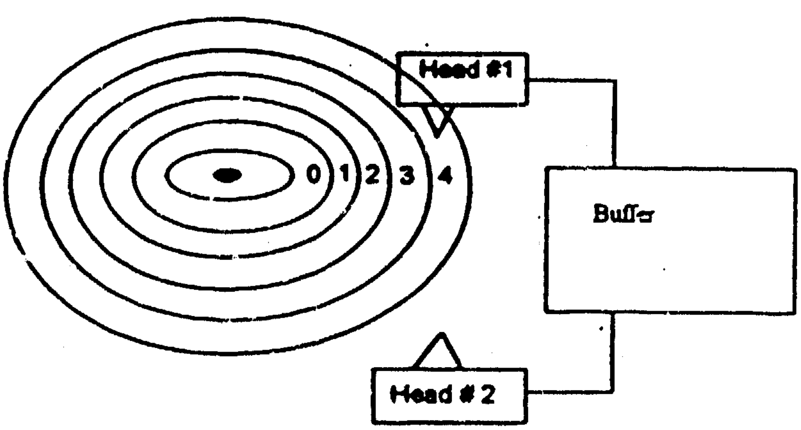


Figure D-4 Organization & Technical Requirements

Disk Organization

Band	Inner Radius	Outer Radius	RPM	Min Velocity (m/s)	Max Velocity (m/S)	Tracks per Band	User KBytes/ Track	User MBytes/ Band
0	70	91	1826	13.38	17.4	14000	49.3	690.1
1	91	112	1405	13.38	16.5	14000	64.1	897.1
2	112	133	1141	13.38	15.9	14000	78.9	1104.2
3	133	154	961	13.38	15.5	14000	93.7	1311.2
4	154	175	830	13.38	15.2	14000	108.4	1528.2
								5530.8

Technical Requirements

Reliable data recording and playback for (1,7) encoded data at 14.87 Mb/s (channel), or 12 Mb/s (user).

(1,7) code: rate 2/3

Minimum mark: 1.2 um 2/3(1+1)/1.2 = 1.111 bits/um

Channel bit = 1.2 um / [2*(13.38 m/s)] = 44.843 nS

Minimum mark = 89.69 nS

Track pitch: 1.5 um or better

Figure D-5 Capacity vs. Inner Usable Radius

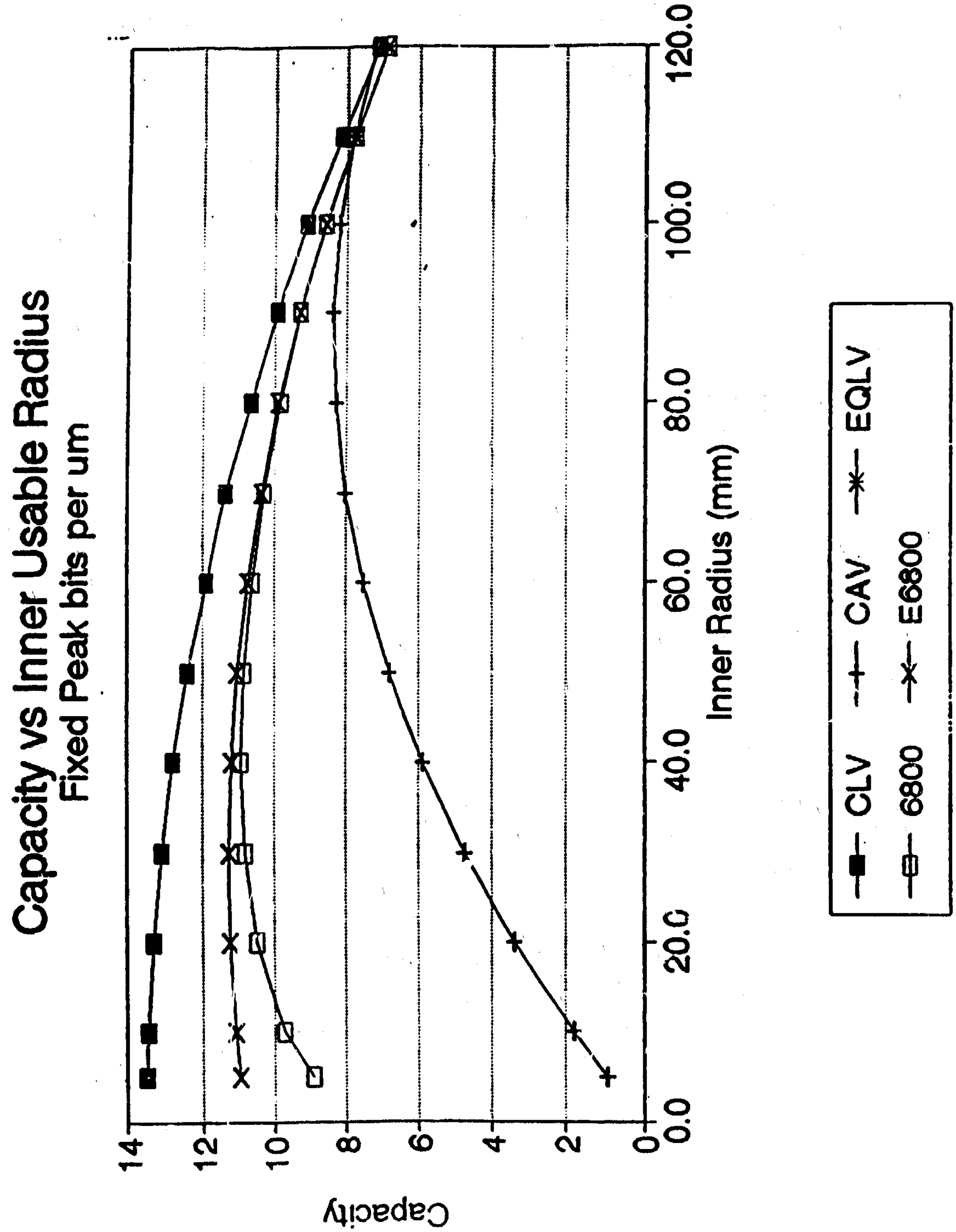
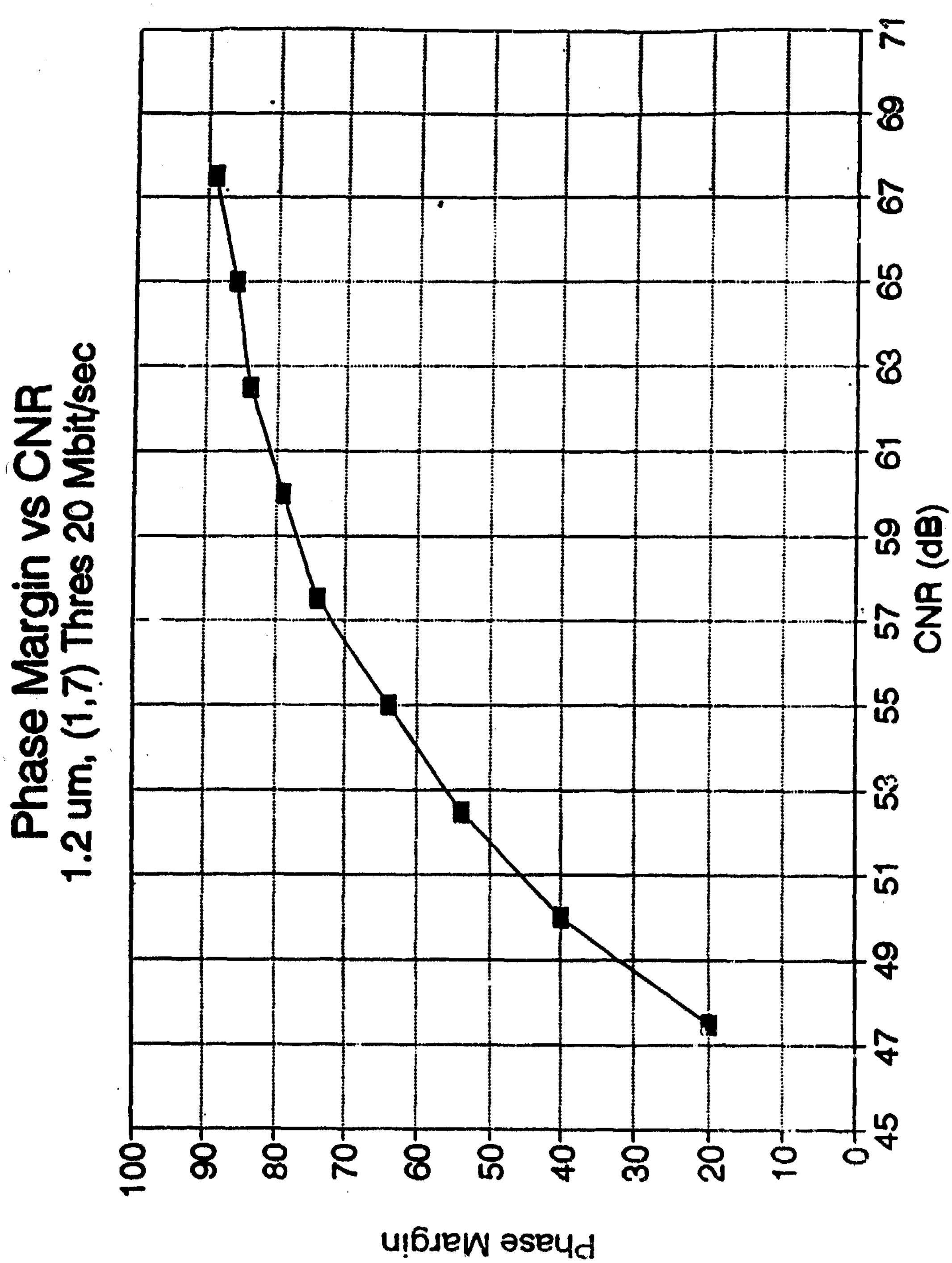


Figure D-6 Phase Margin vs. CNR



Appendix E Write-Once System Performance

Figure E-1 Write-Once Carrier-to-Noise Ratio

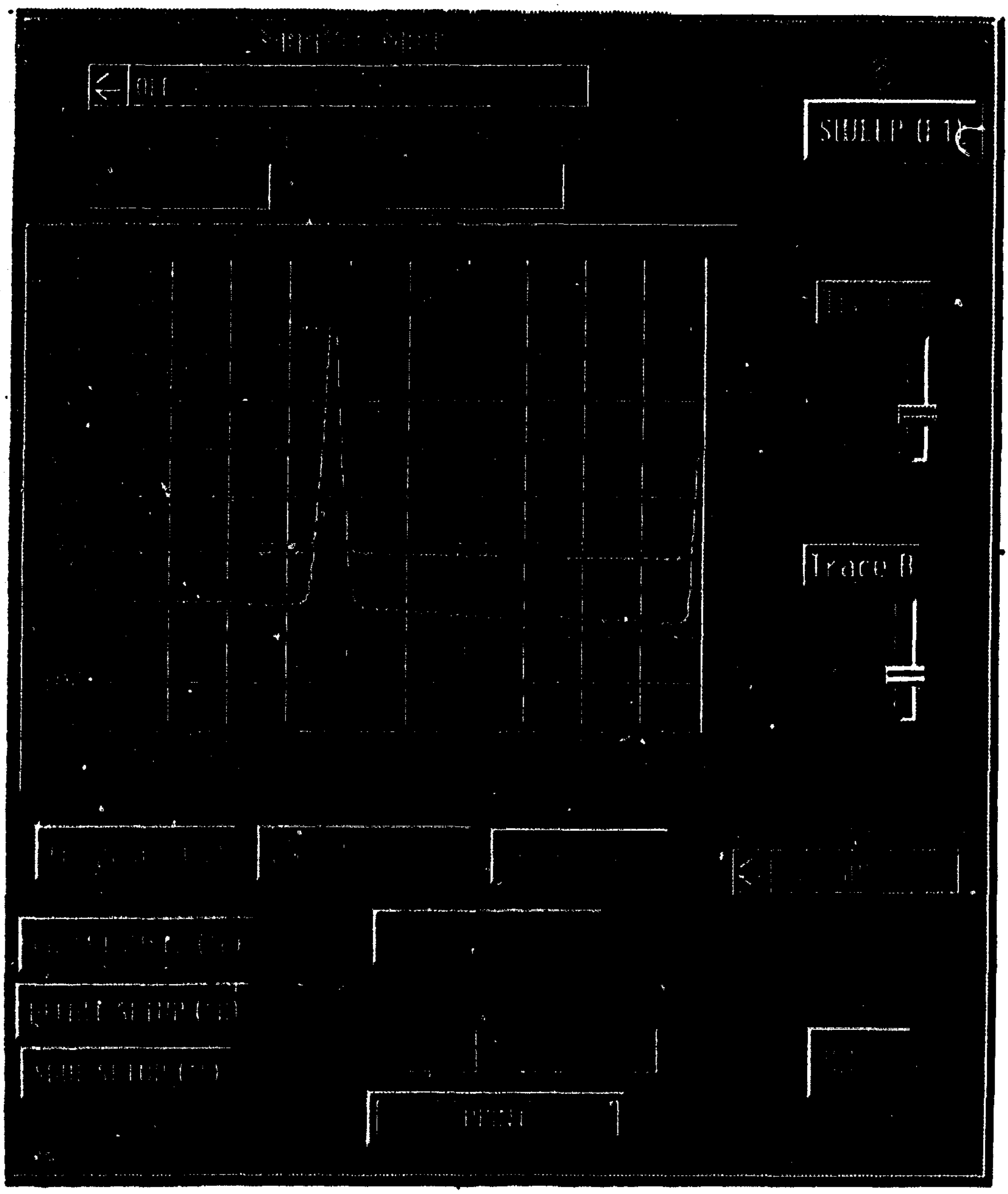


Figure E-2 Write-Once Time Interval Analysis of a Tone

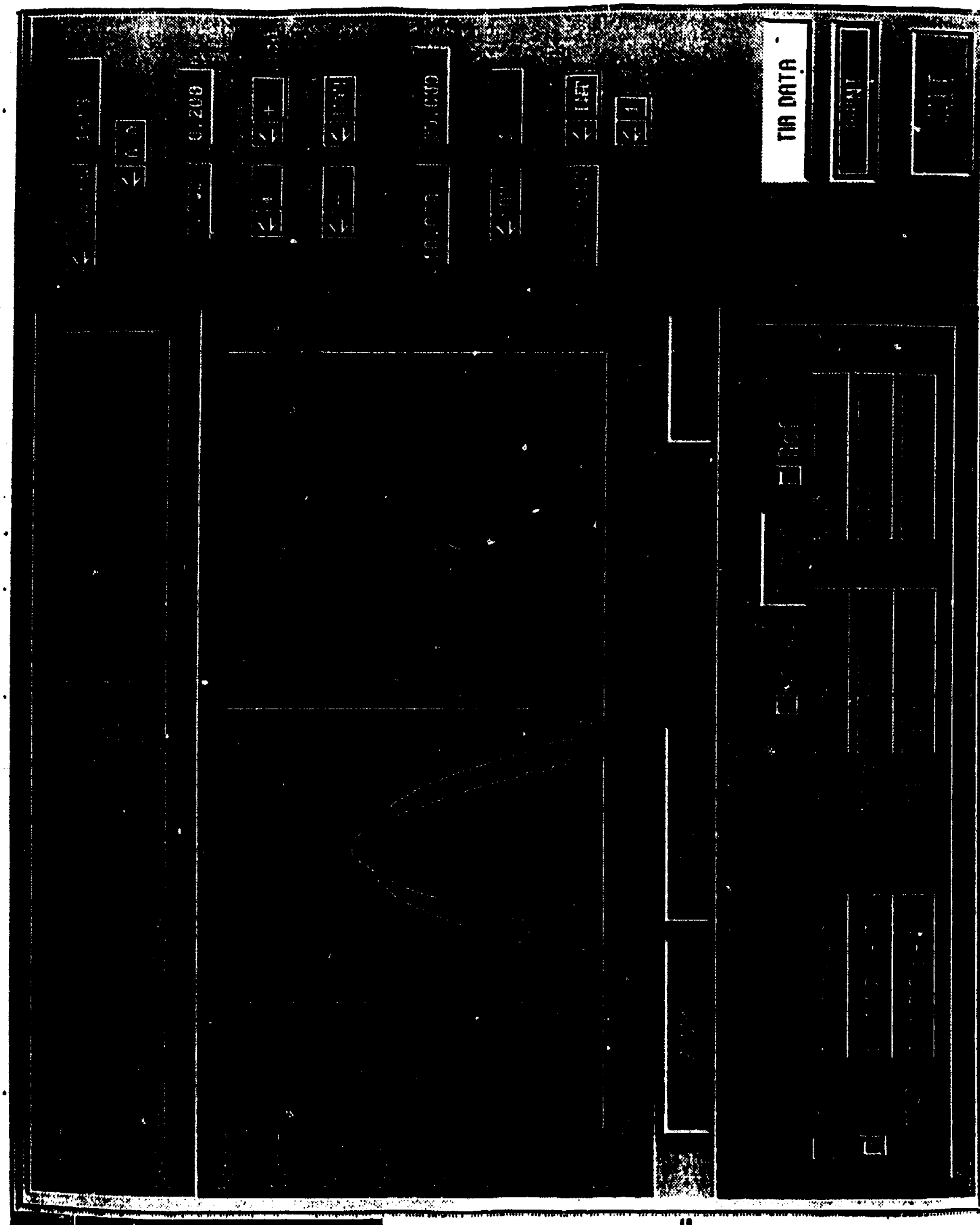
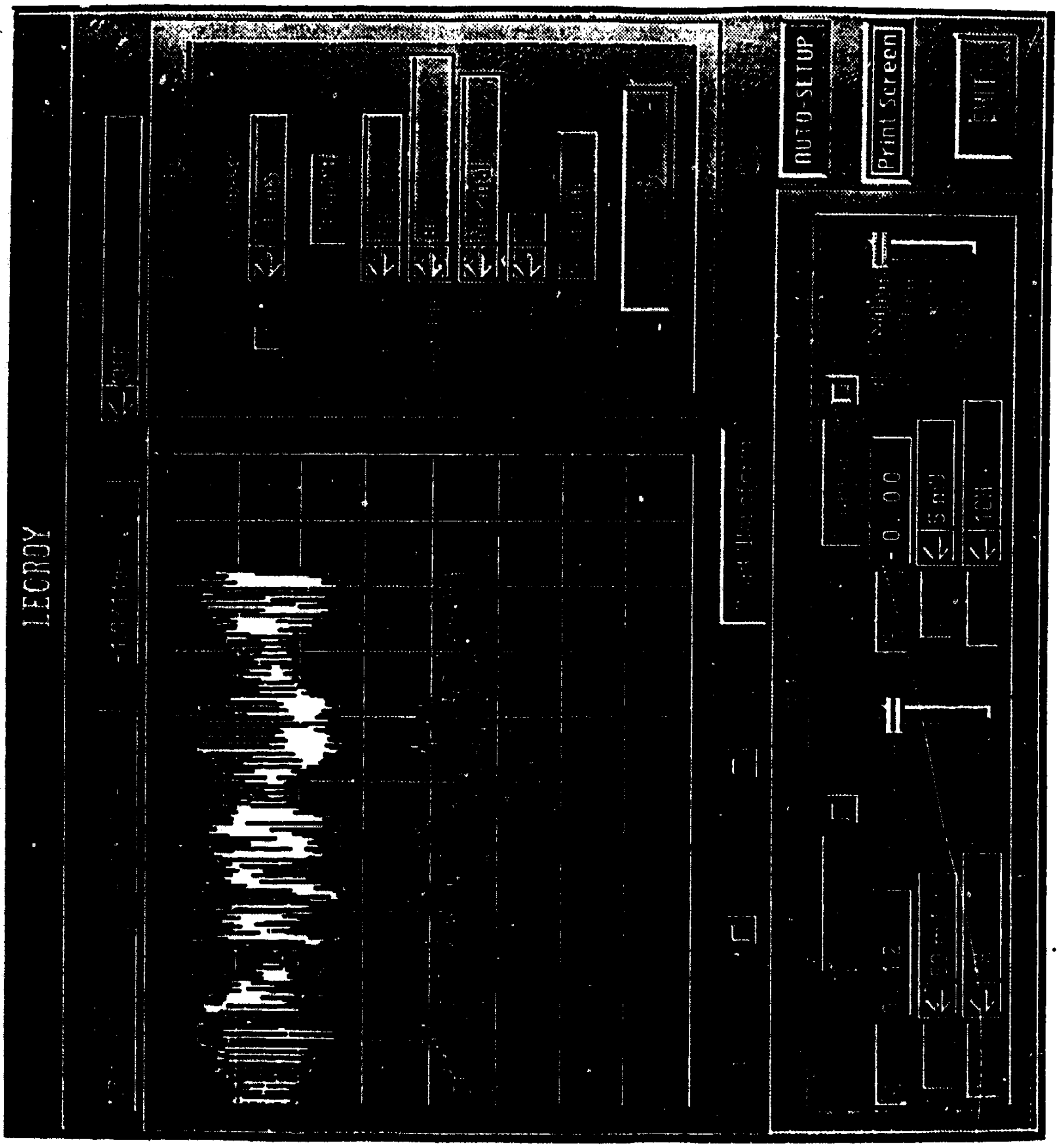


Figure E-3 Write-Once Mistracking Waveform



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